Volume 20 MARCH, 1936 Number 3

BULLETIN
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American Association *of* Petroleum Geologists

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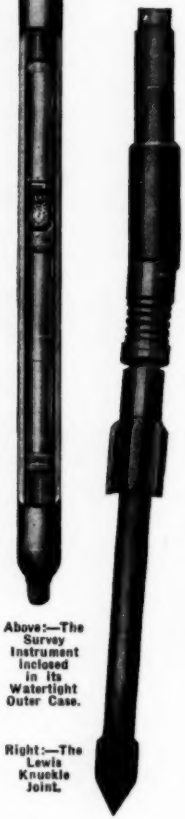

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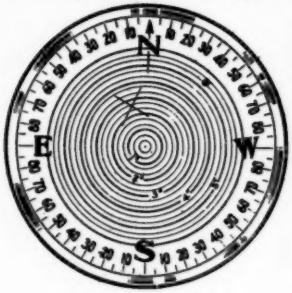

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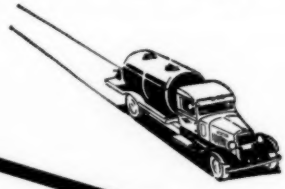

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Volume 20 Number 3

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

MARCH, 1936

PROPORTION OF ORGANIC MATTER CONVERTED INTO OIL IN SANTA FE SPRINGS FIELD, CALIFORNIA[1]

PARKER D. TRASK[2]
Washington, D. C.

ABSTRACT

All the oil that was in the Sante Fe Springs field at the time the field was discovered is equivalent to a yield of 0.053 per cent of the weight of the prism of sediments from which the oil seems to have been derived. As the organic content of these sediments at time of deposition is calculated to be 3.0 per cent of the weight of the sediments, the yield of oil would be 0.053/3.0 or 1.8 per cent of the organic content of the sediments. This represents the minimum production of oil by the organic matter. The actual quantity that was generated by the source beds presumably was larger, as some oil that was formed may have failed to reach the reservoir. When the possible sources of loss of oil, such as retention by source beds, escape to the surface of the ground, destruction by bacteria, and trapping and adsorption while migrating, are considered, the conclusion is reached that the most probable yield of oil by the organic constituents is of the order of magnitude of 4 per cent, though the yield may have been as high as 15 per cent.

INTRODUCTION

A pertinent question in connection with the problem of the origin of oil is how much of the organic content of the source beds is converted into petroleum. It is not yet possible to state definitely the proportion of the organic matter in the sediments that is transformed into oil in any particular field, but recent studies of the Santa Fe Springs field in California, in connection with investigations of source beds sponsored by the American Petroleum Institute and the United States Geological Survey, have yielded information which makes it possible to estimate the order of magnitude of the amount converted

[1] Published by permission of the director of the United States Geological Survey. Read before Pacific Section of the Association at Los Angeles, November 8, 1935. Manuscript received, January 31, 1936.

[2] United States Geological Survey.

in this field. The quantity presumably varies among different fields, but it is beyond the scope of this paper to consider areas other than Santa Fe Springs.

In order to calculate the quantity of organic matter that is converted into oil the following questions have to be answered: (1) what is the volume of the source beds from which the oil came; (2) how much oil accumulated in the field; (3) what is the percentage of organic matter in the sediments; (4) how uniformly is the source material distributed among the sediments; (5) how much oil is lost during migration? The first three questions and possibly the fourth can be answered fairly satisfactorily for the Santa Fe Springs field, but the fifth, namely, how much oil fails to accumulate in the reservoir, is at present difficult to answer.

VOLUME OF SOURCE BEDS

The volume of sediments from which the oil in the Santa Fe Springs field seems to have been chiefly derived represents a prism of rock approximately 50 square miles in area and 4,200 feet thick. The Santa Fe Springs field is located in the northeast part of the Los Angeles basin on a doubly plunging anticline.[3] This anticline is bounded on either side by synclinal axes, one lying 2 miles northeast of the anticlinal axis and the other 6 or 7 miles southwest. The crest of the anticlinal axis pitches for about 2.5 miles southeast and 3 or 4 miles northwest where it presumably is cut by a fault. The producing area within the field is not faulted and the flanks of the anticline presumably also are not faulted. The only chance for entrance of oil along fault planes seems to be on the possible fault that limits the northwest edge of the area from which the oil could be drained, but it is not clear as to whether the anticline pitches as far as this postulated fault before rising again. The region which could supply oil to the field therefore occupies an area about 6 miles long and 8.5 miles wide, or approximately 50 square miles.

The sediments that generated the oil seem to be confined largely to the same sequence of strata as those in which the oil is found. Oil

[3] J. B. Case, "Report on Santa Fe Springs Oil Field," *California State Div. Mines Summ. Operations, California Oil Fields*, Vol. 8, No. 11 (1923), pp. 5–19.

R. R. Templeton, and C. R. McCollom, "Santa Fe Springs Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 178–94.

A. B. Hendrickson and D. K. Weaver, "Santa Fe Springs Oil Field," *California State Div. Mines, Summ. Operations, California Oil Fields*, Vol. 14, No. 7 (1929), pp. 5–21.

J. Jensen, G. McDowell, W. D. Goold, and M. L. Gwin, "Deep Sand Development at Santa Fe Springs," *Petroleum Development and Technology, 1930* (Amer. Inst. Min. Met. Eng.), pp. 310–21.

H. W. Hoots, "General Geology of the Los Angeles Basin," *16th Intern. Geol. Congr. Guide Book 15* (1933), pp. 23–26.

is encountered in the field in 8 zones which on the crest of the anticline lie between depths of 3,500 and 7,700 feet. The lower 300 feet of the producing beds are Miocene and the upper 3,900 feet are Lower Pliocene. The individual producing zones are underlain by water of different head and are bounded by impervious shale caps. The shale a few feet above the top of one of the zones (Buckbee) contains less than 0.02 per cent of material soluble in carbon tetrachloride, which is among the smallest yields that have been observed among many hundreds of ancient (lithified) sediments the writer and his associates have analyzed. As petroleum is readily soluble in carbon tetrachloride, it seems that little oil is migrating through the shale cap rock.

The ratio of the quantity of oil in the individual zones to the quantity of organic matter in the sediments within the zones[4] is approximately constant in the lower five zones of the field. If the oil were derived mainly from the Miocene sediments beneath the oil zones, the ratio of oil to organic content presumably should progressively decrease upward. Similarly the sediments above the oil zones are conspicuously barren, though sands which could act as reservoirs are present. A zone of gas under considerable pressure lies 1,500 feet above the uppermost oil zone, yet no oil has yet been found associated with this gas.

The localization of the oil into zones, the difference in pressure among the zones, the approximate constancy of the ratio of oil to organic matter in the lower five zones, the lack of oil in sands above a depth of 3,500 feet on the crest of the structure, and the apparent absence of faults which could afford suitable channels for migration seem to indicate that the oil is derived largely from the same sequence of strata as those in which it is found.

The thickness of the strata regarded as the source beds on the crest of the anticline may be considered as indicating approximately the average thickness for the entire drainage area for the field. The thickness apparently does not change appreciably in directions parallel with the anticlinal axis, as it is approximately the same in wells located on the axis a few miles southeast of the Santa Fe Springs field. The beds, however, presumably thin toward the northeast normal to the axis in the direction of the shore line at the time the sediments were laid down. They also apparently thicken southwestward toward the center of the basin in which they were deposited. Whether or not they thicken progressively from the axis of the anti-

[4] P. D. Trask and H. E. Hammar, "Results of the American Petroleum Institute Research Project on Origin and Environment of Source Beds," *Proc. Amer. Petrol. Inst.*, Vol. 14 M (IV), (1933), p. 26 (*Prod. Bull. 211*).

cline as far as the axis of the syncline that forms the southwestern limit of the drainage area is problematical, because in the Dominguez and Long Beach fields, 12–15 miles southwest of the Santa Fe Springs field, this sequence of rocks is at least 1,000 feet thinner than at Santa Fe Springs.[5] Therefore, despite the greater width of the southwest flank of the anticline, the increase in thickness on this flank may not appreciably overbalance the decrease in thickness on the northeast flank. The figure of 4,200 feet, which represents the thickness on the crest of the anticline, accordingly may be considered as indicating the order of magnitude of the average thickness of the sequence of sediments that supplied the oil for the field.

OIL CONTENT OF FIELD

The Santa Fe Springs field, to the end of December, 1934, had produced 385,000,000 barrels of oil and the estimated gross oil reserves were 70,000,000 barrels,[6] making the ultimate recovery 455,000,000 barrels. If one-third the oil is assumed to be recoverable and two-thirds to remain in the ground after the field has been exhausted, then the initial oil content of the field would be $3 \times 455{,}000{,}000$ or 1,365,000,000 barrels.

REQUISITE YIELD OF OIL FROM SEDIMENTS

The proportion of the weight of the sediments that has been transformed into oil can be calculated from the initial oil content of the field and the volume of possible source beds. The oil content is taken to be 1,365,000,000 barrels and the volume of source beds as a prism of rock 4,200 feet thick and 50 square miles in area. Hence a block of sediments 1 foot thick and 1 mile square would have to produce $1{,}365{,}000{,}000/(4{,}200 \times 50)$ or 6,500 barrels of oil, and 1 cubic foot would have to yield $6{,}500 \times 42/(5{,}280 \times 5{,}280)$ or 0.0098 gallon of oil. On the assumption that the average density of the sediment is 2.1, a cubic foot would weigh 62.5×2.1, or 131 pounds. The average gravity (A.P.I.) of the oil in the field is about 34°; 1 gallon therefore would weigh 7.12 pounds and 0.0098 gallon would weigh 0.070 pound. Thus 1 cubic foot or 131 pounds of sediment would yield 0.07 pound of oil. One pound of sediment accordingly would produce $0.07/131$ or 0.00053 pound of oil. That is, the requisite yield of oil would be 0.053 per cent of the weight of the sediment.

[5] H. W. Hoots, *op. cit.*, p. 24.

[6] V. H. Wilhelm, "Developments in the California Oil Industry during the Year 1934," *Petroleum Development and Technology, 1935* (Amer. Inst. Min. Met. Eng.), p. 265.

ORGANIC CONTENT OF SEDIMENTS

The proportion of the organic matter that has to be transformed into petroleum in order to account for the quantity of oil in the field therefore can be calculated provided the quantity of organic matter in the sediment is known. The average organic content of the 4,200 feet of sediments regarded as the source of the oil in the Santa Fe Springs field is 1.5 per cent.[7] Sediments of similar age in oil fields located along the same anticlinal axis as that on which the Santa Fe Springs field lies, likewise contain about 1.5 per cent organic matter.[8] In the fields such as Seal Beach, Long Beach, and Dominguez, located along the next anticlinal axis southwest of the anticline on which the Santa Fe Springs field is situated, the sediments of the same age as the beds regarded as the source of oil in the Santa Fe Springs field contain 3.0–3.5 per cent organic matter. The drainage area for the Santa Fe Springs field extends 6 miles west and only 2 miles north. As the lines of equal organic content are approximately parallel with the axis of the anticline, the average organic content of the source beds in the drainage area is equivalent to the organic content of the sediments lying on a line parallel with the axis of the anticline 2 miles west of the center of the field. If the rate of change in organic content between the Santa Fe Springs and Long Beach fields is uniform, the organic content along this line would be 1.8 per cent.

The increase in organic content from the Santa Fe Springs field southwest toward the Long Beach field may not be uniform. The organic content may possibly reach a maximum along the synclinal axis between the two fields and decrease toward each field, with the result that the average organic content of the drainage area for the Santa Fe Springs field might be greater than 1.8 per cent.[9]

The sediments in both the Santa Fe Springs and Long Beach fields seem to be richer in sand than correlative sediments on the flanks of the anticlines on which these fields are located. If the anticlines with which these two fields are associated were in the process of formation while the Pliocene sediments that are regarded as the source of the oil were accumulating, the deposits on the crests of the anticlines would probably be sandier than those deposited along the flank. Studies of the recent sediments have shown that sediments deposited on protuberances and ridges on the sea floor commonly are sandier than

[7] P. D. Trask and H. E. Hammar, *op. cit.*, p. 27.

[8] P. D. Trask and H. E. Hammar, "Organic Content of Sediments," *Drilling and Production Practice, 1934* (Amer. Petrol. Inst., 1935), p. 123.

[9] A suggestion made by R. D. Reed in conversation with writer.

those deposited in basins or on the sides of such ridges.[10] Thus the sandy nature of the sediments on the crests of the Santa Fe and Long Beach fields would be in accord with the concept that the anticlines on which these fields are located were growing while the sediments were being deposited.

If the anticlines grew gradually during deposition of the sediments, the organic content of the sediments in the basin or depression between the anticlines would be larger than that of the sediments on the anticlinal axes.[11] If the average organic content in the bottom of the syncline should be as much as 5 per cent, which is about the maximum the writer has observed for such a thick sequence of sediments, the average organic content of the drainage area for the Santa Fe Springs field would be 2.67 per cent instead of 1.8 per cent. The true average therefore may be considered as probably lying between these limits, but until samples from the bottom or the flanks of the syncline have been actually analyzed and show such a trend toward greater organic content in the synclinal trough, it seems better to use the estimate of 1.8 per cent, with the understanding that the real average possibly might be as high as 2.67 per cent.

The initial organic content, that is the quantity of organic matter that was in the sediments at time of deposition, however, is greater than the present organic content. It is difficult to estimate what the initial organic content of any particular sequence of ancient sediments may be. The average quantity of organic matter among recent sediments as indicated by a study of nearly 2,000 samples from many parts of the world is 2.5 per cent and the average organic content of several thousand samples of ancient sediments, ranging in age from Cambrian to Pleistocene from many parts of the United States, is 1.5 per cent.[12] If these averages are indicative of sediments in general—and the number of samples analyzed is sufficiently large to give some assurance that they may be—then the decrease in organic content during burial of the sediments would be 2.5 minus 1.5, or 1.0 per cent, and the percentage loss would be 1.0/2.5, or 40 per cent. This of course is an average figure. Under different conditions some sediments would lose less and others would lose more. In the absence of data to the contrary this loss of 40 per cent seems to be applicable to the sediments from the Santa Fe Springs field, but the relatively short

[10] P. D. Trask, "Sedimentation in the Channel Islands Region, California," *Econ. Geol.*, Vol. 26 (1931), pp. 24–43.

[11] P. D. Trask, *Origin and Environment of Source Sediments of Petroleum*. Gulf Publishing Company, Houston, Texas (1932), p. 122.

[12] P. D. Trask and H. E. Hammar, "Organic Content of Sediments," *Drilling and Production Practice, 1934* (Amer. Petrol. Inst., 1935), p. 128.

time they have been buried might indicate that the loss was less than 40 per cent.

The sediments in the Santa Fe Springs area presumably were deposited under conditions similar to those under which sediments are now being laid down in the Channel Island region a few miles southwest of the Santa Fe Springs field. The average organic content of the sediments in the Channel Islands area is about 3.4 per cent[13] compared with 1.8 per cent for the sediments in the Santa Fe Springs field drainage area. If the initial organic content of the sediments in the Santa Fe Springs field were similar to that of the recent sediments, the loss during deposition would be 1.6/3.4, or 47 per cent.

The decrease in organic content of the sediments in the Santa Fe Springs field, accordingly would seem to be of the order of magnitude of 40 per cent. The present content of organic matter would therefore be 60 per cent of the original quantity, which would be 1.8/0.6, or 3.0 per cent. This figure of course is based on the assumption that the sediments are average sediments and that they were deposited under conditions similar to those under which the sediments in the Channel Islands are now accumulating. It certainly would be difficult, however, to disprove that the initial organic content was as low as 2.5 or as high as 4.0 per cent.

If the most plausible (or least objectionable) figure of 3.0 per cent of the total weight of the sediments be taken, the proportion of organic matter that had to be transformed into petroleum to account for the oil in the Santa Fe Springs field would be 0.53/3.0, or 1.8 per cent. If the initial organic content were 2.5 per cent the proportion would be 0.053/2.5, or 2.1 per cent, and if it were 4.0 per cent it would be 0.053/4.0, or 1.3 per cent. The minimum conversion of organic matter into oil therefore presumably lies between 1.3 and 2.1 per cent and probably is about 1.8 per cent.

QUANTITATIVE DISTRIBUTION OF SOURCE MATERIAL AMONG SEDIMENTS

The foregoing estimate of 1.8 per cent holds provided the source material for the oil is distributed uniformly among the 4,200 feet of sediments regarded as source beds. The sediments throughout this sequence of strata naturally vary in organic content, but this variation in organic content will have no effect on the validity of the results if the same proportion of organic matter is converted into oil in all the sediments. It is probable, however, that some sediments vary in their ability to generate oil. Sands, because of the greater chance for oxidation during deposition, possibly may yield less oil, with respect

[13] P. D. Trask, *op. cit.*, p. 284.

to their organic content, than silts or clays. Moreover, different sediments may contain different proportions of source materials. In the absence of knowledge of what substances actually do generate oil it is very difficult to answer the question of distribution of source material throughout this thick sequence of sediments.

The data at hand, however, support the concept that the proportion of source material is fairly constant throughout the 4,200 feet of strata, as is shown by (1) the similar ratio of oil content to quantity of organic matter in most of the oil zones in the Santa Fe Springs field; (2) the similar content of organic matter; (3) the similar volatility of the organic constituents; and (4) the similar carbon-nitrogen ratio throughout the different oil zones. The possibility, however, must be entertained that the conversion of organic matter into oil has been greater in some beds than in others.

FAILURE OF OIL TO MIGRATE

The discussion thus far has not considered the oil that fails to accumulate in the reservoir. It is evident that some oil that is generated by the source beds does not reach the oil pool, but the quantity is difficult to estimate. The oil may remain in the sediments after it was formed, it may escape to the surface of the ground, it may be destroyed *en route* to the reservoir, or it may be adsorbed as it migrates.

The quantity of oil in the Santa Fe Springs field is estimated to represent a yield of 1.8 per cent of the organic content of the sediments in the drainage area of the field. The amount that failed to accumulate almost certainly is equivalent to 0.2 per cent of the organic content of the sediments. The total yield of oil, therefore, is at least 1.8 plus 0.2, or 2 per cent of the original organic content of the source beds.

The yield, however, may be much greater than 2 per cent. The loss in weight of the organic content of the sediments while buried in the ground presumably is of the order of magnitude of 40 per cent. Not all of this 40 per cent is due to material that has been transformed into petroleum, as part of it represents decomposition products, such as water and carbon dioxide. As petroleum has such a specialized composition compared with the organic constituents of sediments, it seems improbable that more than one-third of the loss in organic matter would represent petroleum. The maximum conversion of organic matter into oil accordingly would be of the order of magnitude of 40/3, or 15 per cent. It must be remembered, however, that this figure depends on the loss in organic matter during burial of the sediments.

The yield of oil therefore presumably lies between 2 and 15 per cent of the organic content. Any attempt to estimate the actual proportion would be little more than a guess. The various possible sources of loss of oil, however, can be considered and some idea of the quantity of oil that fails to reach the reservoir can thereby be obtained.

Retention of oil by source beds.—Some of the oil may be retained by the source beds and never accumulate in the pool. In the Santa Fe Springs field the quantity of such oil presumably is small, as the bitumen content of the fine-grained sediments in the field is approximately the same as in ordinary sediments that are not necessarily regarded as source beds. The bitumen content refers to the percentage of material soluble in carbon tetrachloride or ether. A large part, if not most, of the material soluble in carbon tetrachloride in sediments represents substances other than petroleum. In fact the average bitumen content of fine-grained sediments now being deposited beneath the sea is 0.06 per cent, yet these sediments contain little or no petroleum.[14] Various types of ancient sediments contain similar quantities of bitumen (Table I). The average (median) bitumen content of the fine-grained Pliocene sediments from the Santa Fe Springs field is 0.07 per cent. The content of petroleum in these sediments therefore presumably represents the excess over the bitumen content of normal sediments, namely, 0.07 minus 0.06, or 0.01 per cent. As the sediments lie on the crest of the anticline, they contain oily materials that have migrated into them. The strata down the dip beyond the edges of the oil zones, therefore, presumably would contain less bitumen than 0.07 per cent. Consequently the quantity of free oil now in the source beds for the field would probably be less than 0.01 per cent; perhaps 0.005 per cent would be a proper estimate.

TABLE I

BITUMEN CONTENT OF SOME FINE-GRAINED SEDIMENTS

Type of Sediment	*Number of Samples*	*Median Bitumen Content*
		Per Cent of Entire Sediment
Representative recent marine sediments	20	0.06
Pliocene—Venice (California) oil field	19	0.04
Pliocene—Santa Fe Springs field	115	0.07
Miocene—Santa Fe Springs field	67	0.06
Cretaceous outcrops—northern California	23	0.05

As 0.053 per cent of the weight of the sediments represents the quantity of oil originally in the Santa Fe Springs field, the amount of

[14] P. D. Trask and C. C. Wu, "Does Petroleum Form in Sediments at Time of Deposition," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 1451–53.

oil retained by the sediments would be 0.005/0.053, or 10 per cent of the oil now in the field. This estimate of course is no more than a crude approximation, and serves to indicate that the quantity of oil that failed to migrate out of the source beds probably represents only a small proportion of the quantity that reached the reservoir.

Escape of oil.—Oil may have escaped up the dip before the anticline began to grow. As the anticline seems to have begun to form at the time the sediments were deposited or relatively soon thereafter, comparatively little oil probably escaped to the surface of the ground. As the field apparently is free from faults and as the shaly layers above the oil zones presumably are practically impervious to oil, the quantity of oil that has been lost by migrating across the bedding in all likelihood is small.

It is difficult to estimate the amount of oil that may have been lost in these ways, but 50 per cent of the quantity that was originally in the field seems a fair figure, though if the anticline was growing while the sediments were being deposited, as seems likely, the quantity would probably be smaller than 50 per cent.

Bacterial destruction of oil.—Petroleum possibly may be destroyed by anaerobic bacteria while underground. McCoy and Keyte seem to think it can, but White does not.[15] Ginzburg-Karagitscheva[16] observed that the micro-organisms recovered from oil wells grew best on the particular concentration of salt that was in the water associated with the oil. Ginter[17] reports that the sulphate content of some oil-field brines increases away from the edge of the oil pool. It therefore seems possible that bacteria can exist in the vicinity of oil fields. It does not necessarily follow, however, that the micro-organisms live on petroleum. They may live on organic substances that contain more oxygen than petroleum. Waksman[18] points out that anaerobic bacteria tend to take oxygen away from organic compounds rather than add oxygen to them as would be required if petroleum hydrocarbons which contain no oxygen were the source of food for the bacteria.

[15] A. W. McCoy and W. R. Keyte, "Present Interpretations of the Structural Theory for Oil and Gas Migration and Accumulation," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 262–68.
D. W. White, "Metamorphism of Organic Sediments and Derived Oils," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), p. 606.

[16] T. L. Ginzburg-Karagitscheva, "Microflora of Oil Waters and Oil-Bearing Formations and Biochemical Changes Caused by It," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), pp. 62–65.

[17] R. L. Ginter, "Sulphate Reduction in Deep Subsurface Waters," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 907, 924.

[18] S. A. Waksman, "Principles of Soil Microbiology," Williams & Wilkins Company, Baltimore (1927), pp. 409, 462.

Moreover, if petroleum is destroyed by bacteria, it must be destroyed mainly while it is migrating to the reservoir. So little free or combined oxygen is present within the mass of oil in the reservoir, that the bacteria could not live on the inside of the pool. Petroleum could be destroyed by bacteria on the edges of a pool, but the quantity of oil lying near enough to the border of the pool to be acted upon by bacteria is small compared with the main mass of oil, which presumably had to migrate in a disseminated form.

If the oil migrated as small droplets, bacteria would have ample opportunity of obtaining oxygen from sulphate or other sources from the water that surrounded the droplets. Therefore, if bacteria did destroy oil underground, it is difficult to understand why they would not completely decompose the oil before it ever reached the reservoir; but since the oil does accumulate in the pools, the presumption arises that the bacteria do not destroy much oil as it migrates. The oil, however, possibly may migrate as masses of oil, in which case bacteria, if present, though perhaps incapable of decomposing all the oil before it reaches the reservoir, possibly might destroy a considerable proportion of the oil as it migrated.

Moreover, the temperature in the drainage basin may have been too high for bacterial life. According to data presented by Van Orstrand,[19] the temperature is about 135°F. at a depth of 3,500 feet, which is the top of the producing zones on the crest of the anticline, and it is approximately 215°F. at a depth of 7,700 feet, which is the base of the producing zones. Down the dip away from the area of production the temperatures are higher. The average temperature of the prism of rocks regarded as the source of the oil, as indicated by Van Orstrand's data, is about 212°F. Bacteria have been reputed as being able to grow at temperatures nearly to the boiling point, but most bacteria do not grow well at a temperature above 135°F. (57°C.), which at present is the coolest temperature in the prism of sediments regarded as the source of the oil.

The question of the action of bacteria on migrating oil therefore is difficult to answer. The probabilities, however, seem to be against much oil being destroyed but the possibility has to be considered that oil can be decomposed as it migrates or after it reaches the reservoir.

Loss of oil by adsorption.—Oil may be trapped or adsorbed while it is migrating toward the reservoir. However, if this were a general process it would seem as if very little oil would ever accumulate in pools. Furthermore, the remarkably clean character of many water-

[19] C. E. Van Orstrand, "Temperature Gradients," *Problems of Petroleum Geology*, *ibid.*, p. 1011.

bearing sands down the dip in the same beds as those in which the oil occurs, argues against the retention of a large proportion of the oil by adsorption. Moreover, as pointed out by Nutting,[20] base exchange may aid the displacement of adsorbed oil from mineral constituents.

Krejci-Graf[21] believes that petroleum migrates out of source beds only when sufficient mother material is present to generate oil in excess of that which can be adsorbed by the sediments. He postulates, therefore, that source beds must be extremely rich in organic matter. However, the small quantity of organic matter found in all of the many thousand ancient sediments the writer and his associates have studied from numerous oil-producing regions west of the Mississippi River, indicates that extreme richness in organic matter is not an essential requisite.[22] The chances therefore seem to favor a relatively small loss of oil by adsorption during migration; perhaps 50 per cent of the amount of oil that does reach the field.

TOTAL AMOUNT OF OIL GENERATED

Though the destruction or loss of oil by any one of these several processes does not seem large, the total for all of them may amount to a considerable quantity in comparison with the oil that is generated by the source beds. In the foregoing discussion the quantities of oil lost in the various ways that were considered total 110 per cent of the oil in the field; namely—retained by source beds, 10 per cent; escaped to the ground, 50 per cent; destroyed by bacteria, 0 per cent; adsorbed during migration, 50 per cent. If this figure of 110 per cent is accepted as indicating the order of magnitude of the quantity of oil that fails to accumulate, then the total quantity of oil produced by organic constituents of the source beds would be 210 per cent of the oil originally in the field; that is, the yield of oil by the source beds would be 2.1×1.8, or 4 per cent. However, this figure of 4 per cent seems to be scarcely more probable than some other figure of the same order of magnitude, such as 3 or 7 per cent. A yield of oil in excess of 7 per cent would indicate that only $1.8/7$, or 25 per cent of the oil accumulated in the reservoir and 75 per cent was lost. The loss of this large quantity of oil, though possible, seems distinctly less probable than the loss of a smaller amount.

[20] P. G. Nutting, "Some Physical and Chemical Properties of Reservoir Rocks Bearing on the Accumulation and Discharge of Oil," *Problems of Petroleum Geology, ibid.*, pp. 825–32.

[21] K. Krejci-Graf, "Grundfragen der Oelgeologie," *Schrift. Gebiet Brennstoff-Geol.*, Heft 4 (1930), pp. 1–179.

[22] P. D. Trask and H. E. Hammar, "Organic Content of Sediments," *Drilling and Production Practice, 1934* (Amer. Petrol. Inst., 1935), p. 128.

The quantity of organic matter that is transformed into oil in the Santa Fe Springs field, therefore, almost certainly is not less than 2 per cent and probably is not much more than 15 per cent of the original organic content of the sediments. If a single figure, rather than probable limits, is to be given, 4 per cent seems to be the least objectionable. The calculations of these figures are based in part on assumptions, but with the exception of the quantity of oil that fails to accumulate in the reservoir, the data upon which they are based presumably are of the proper order of magnitude. The figure of 4 per cent therefore serves as a first approximation of the amount of organic matter that is transformed into oil in the Santa Fe Springs field. The inference does not follow, however, that the source beds in this field have generated all the oil that they can generate, or that the yield of oil is the same in other fields. Nevertheless, it does seem that in the Santa Fe Springs field only a very small proportion of the organic matter has to be transformed into oil to account for the oil in the field.

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VERTICAL DISTRIBUTION OF BACTERIA IN MARINE SEDIMENTS[1]

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ABSTRACT

Off the coast of Southern California bacteria are more abundant in marine sediments than in the overlying water, there being thousands to millions per gram of sediment and only a few hundred or less per milliliter of water. The distribution of bacteria in the sediment is more or less independent of the depth of the overlying water, the temperature of the ocean floor, and the distance from mainland. The bacterial population seems to be influenced more greatly by the organic content of the sediments than by other factors. Vertical sections from cores 40 to 75 cm. in length show that the number of bacteria in the sediments decreases greatly with depth in the upper 5 cm. of the core and more slowly beyond. In the surface slime, aerobes are 5 to 100 times more plentiful than anaerobes, but at depths exceeding 15 centimeters about as many anaerobes as aerobes are present. Both anaerobes and aerobes have been demonstrated at all depths analyzed. The oxidation-reduction potential (intensity factor expressed as E_h) increases with core depth, although the oxygen-absorbing capacity decreases with depth. Both properties are ascribed primarily to bacterial activity. Bacteria recovered from marine sediments exhibit many biochemical processes such as ammonification, proteolysis, nitrate reduction, nitrification, urea fermentation, chitin digestion, methane production, fat hydrolysis, cellulose decomposition, glucose, xylose, and arabinose fermentation and starch hydrolysis.

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INTRODUCTORY REMARKS BY PARKER D. TRASK

The alteration of the organic constituents of marine sediments at time of deposition is an influential factor in the origin of petroleum. Micro-organisms are the main agents which cause changes in the organic substances in sediments. Accordingly, this paper on the vertical distribution of bacteria in marine sediments, which Claude E. ZoBell and D. Q. Anderson of the Scripps Institution of Oceanography have kindly consented to prepare for the Association, should be of interest to petroleum geologists. The investigations of Dr. ZoBell and his co-workers are still in a preliminary stage, and this paper reports only the present status of the problem.

He has demonstrated that the quantity of bacteria decreases very greatly from the surface of the deposits downward and that the state

[1] Manuscript received, January 13, 1936.

[2] Scripps Institution of Oceanography, University of California.

of reduction of the organic content of the sediments increases with depth. His work also seems to indicate that the greatest amount of decomposition takes place before or shortly after the organic matter reaches the sea floor and that the organic constituents which do become deposited in sediments are fairly resistant compounds that are not materially altered after they have been buried a few inches. However, the presence of relatively small numbers of bacteria at the greatest core depths that have been reached indicates that micro-organisms may alter the organic matter to some extent for considerable depths beneath the surface of the deposits.

The same inferences are suggested by a comparison of the distribution of organic matter among recent sediments and sedimentary rocks that were deposited in the geologic past. Practically all marine clastic sedimentary rocks contain appreciable quantities of organic matter. In fact, the average organic content of several thousand samples of sedimentary rocks of widely different geologic age from many parts of the United States is 1.5 per cent compared with 2.5 per cent in the surface layers (that is upper 2 or 3 inches) of some 2,000 samples of recent marine sediments from 150 environments of deposition from many parts of the world.[3] The number of samples analyzed is so large and their distribution is so widespread that the averages presumably represent a moderately good approximation of the general organic content of the two types of sediments. Since the average for the sedimentary rocks is 60 per cent of that for the recent sediments, it seems to follow that the organic content of marine sediments ordinarily is not largely destroyed during burial, but instead is preserved to a very appreciable extent.

INTRODUCTION

Bacteria are believed to be the chief agents in the decomposition and transformation of organic matter in marine sediments. They are able to derive their energy from organic matter which other living things can not alter and in so doing regenerate plant nutrients. By their activities bacteria influence the hydrogen-ion concentration, the oxidation-reduction potential, the gas tension and other physico-chemical conditions which have a profound effect on geological, chemical and biological processes (Waksman, 1934). The fragmentary studies which have been made on the bacteriology of bottom sediments indicate that bacteria and closely related micro-organisms may play an important rôle in the precipitation of calcium carbonate (Baven-

[3] Trask, P. D., and Hammar, H. E. "Organic Content of Sediments," *Drilling and Production Practice 1934*, Amer. Petrol. Inst. (1935), p. 128.

damm, 1932), in iron deposition (Harder, 1919), in petroleum formation (Trask, 1932), and in the state of oxidation or reduction of the sedimentary constituents.

Although certain details of the bacteriological technique used by various investigators for collecting and analyzing bottom deposits are so widely divergent that their results are not comparable, the early work is of importance because it demonstrates that the sea floor has a rich microflora at all depths investigated. Certes (1884) found living bacteria in all except four out of 100 sediment samples collected at depths down to 5,100 meters on the Talisman expedition, but his results have no quantitative significance because he used stored samples. The more thorough pioneer studies of Russell (1892) revealed the presence of from 25,000 to 300,000 viable bacteria per milliliter of bottom slime whereas the overlying water seldom contained more than 100 per milliliter. Drew (1912) reported an average of 160,000,000 bacteria per gram of mud and only a few thousand per milliliter of surface water, the number of bacteria decreasing to few or none at 800 fathoms. Lloyd (1931) in the Clyde Sea area and Reuszer (1933) near Cape Cod found many more bacteria in marine sediments than in the overlying water, and they both noted a semblance of bacterial stratification in the mud cores.

EXPERIMENTS

During 1932–1935, 116 bottom-sediment samples have been bacteriologically analyzed. The samples were collected by the boat *Scripps* off the coast of southern California at distances up to 100 miles from the mainland and from depths as great as 2,000 meters. A modified Ekman mud-sampling device as described by Trask (1932) provided cores ranging from 40 to 75 centimeters in length for studying the vertical distribution of bacteria in the bottom deposits. Immediately after being hauled to the surface, uncontaminated central portions from the top, middle, and bottom of the cores were dissected out and transferred to sterile bottles. Exercising aseptic precautions in all manipulations, 3–6 gram sub-samples were weighed into tared bottles and enough sterile sea water added to dilute the mud 1:10. The mud was thoroughly suspended in the water by triturating with a glass rod and shaking vigorously. This suspension, or dilution thereof, was used to inoculate various nutrient media for the estimation of the numbers and kinds of bacteria present.

The nutrient agar employed consisted of sea water to which was added 0.3 per cent bacto-peptone, 0.2 per cent each proteose-peptone and beef-extract, 1.5 per cent agar, and 0.025 per cent $FeCl_3.6H_2O$.

The reaction was adjusted to pH 7.6 with *1/N NaOH*, after which the medium was clarified by filtering through cotton. While it is recognized that this medium does not detect the presence of all viable bacteria, it has been found to yield counts which are from 3 to 80 times as high as those on fish, nutrose, and other media especially recommended for plating marine bacteria (Benecke, 1933). The ferric chloride precipitates from the sea water certain substances which are inimical to the growth of marine bacteria; iron-treated media are clearer, thus facilitating the detection of small colonies; and the iron which remains in solution inherently stimulates the multiplication of the organisms. The proteose-peptone favors the development of many slow-growing bacteria.

The inoculated media were incubated at 21°–23°C. for 5–14 days, or until the plate counts approached constancy. Bacteria from the lower strata of the mud cores require a longer incubation period than those from the uppermost strata and anaerobes develop more slowly than aerobes. The optimum temperature for the multiplication of marine bacteria is 20°–25°C., although many micro-organisms come from the bottoms where the temperature is near zero.

In the water, bacteria are most abundant in the zone 10–50 meters below the surface where there are usually a few hundred per milliliter. At depths below 200 meters very few micro-organisms can be demonstrated except in bottom deposits. The quantity of bacteria in sediments ranges from a few thousand to several million per wet gram. The largest number detected in the uppermost layers of mud was 420,000,000 and only one sample out of the 116 examined contained fewer than 10,000 per gram. Deeper layers were less populous, as is discussed later. Table I shows the vertical distribution of bacteria in sea water at three different stations. The water samples were collected with the bacteriological sampler described by ZoBell and Feltham (1934).

The preponderance of bacteria on the sea bottom has been attributed by various authors to their sinking from above, to more favorable oxidation-reduction conditions, to the beneficial effect of the colloidal state of the mud, to greater freedom from bacteria-feeders, to the preserving action of the lower temperatures encountered in deeper water, and to the concentration of settling organic matter. Corroborating Reuszer's (1933) findings, all evidence indicates that the presence of utilizable organic matter is the most important single factor which influences the distribution of bacteria in marine sediments. However, in certain areas rich in organic matter, bottom-dwelling animals which feed upon bacteria (MacGinitie, 1932) may

restrict the bacterial population, and also many other factors are involved. That the bacteria consume the organic matter nearly as rapidly as it reaches the sea bottom is indicated by the fact that following the storage of marine sediments the order of magnitude of the increase in the bacterial population is only ten- to a hundred-fold whereas many workers (Waksman and Cary, 1935) find that in stored sea water bacteria may multiply until there are several thousand times as many as in the freshly collected sample. In water as well as in mud the increases are related to the content of utilizable organic matter.

TABLE I

AVERAGE NUMBER OF BACTERIA PER MILLILITER OF SEA WATER FROM DIFFERENT DEPTHS AND THE NUMBER PER GRAM (WET BASIS) OF BOTTOM SEDIMENT AS INDICATED BY PLATE COUNTS

Scripps' Station No.		*32A1*	*32B2*	*33A3*
Water Depth		704 Meters	610 Meters	1,287 Meters
Location of station		32° 54.7′N. 117° 26.7′W.	32° 53.5′N. 117° 21.0′W.	32° 32.0′N. 117° 26.5′W.
Sample	*Depth*	*Number of Bacteria*		
Water	1 meter	147	344	261
Water	10 meters	238	400	360
Water	20 meters	292	528	395
Water	50 meters	86	620	208
Water	100 meters	14	17	53
Water	200 meters	3	2	0
Water	500 meters	2	0	0
Sediment	Bottom	2,170,000	768,000	16,200,000

The number of bacteria found in bottom sediments is not influenced by the depth of the overlying water within the limits of these observations (depths to 2,000 meters). In some places there were actually more bacteria in sediments from deep water where the temperature is 3°–7°C. than in those from shallower water where the bottom temperatures are considerably higher. Controlled experiments show that while low temperatures retard the multiplication of bacteria, the low temperatures favor their prolonged survival. ZoBell (1934) has summarized data which show that marine bacteria multiply and are otherwise physiologically active at sub-zero temperatures; therefore, the low temperatures encountered in the oceanic depths would not be a restricting factor. Neither is it probable that the tremendous pressures in deep water limit the bacterial population, because Larsen, Hartzel, and Diehl (1918) have demonstrated the survival of bacteria at 6,000 atmospheres, a pressure approximately six times as great as any in the most abyssal depths. The

actual recovery of bacteria by Certes (1884) and Carey and Waksman (1934) from depths of approximately 5,000 meters proves that neither the hydrostatic pressure nor its release effected by bringing the mud samples to the surface injures the viability of the bacteria.

No relationship was noted between the abundance of bacteria in sediments and the distance from mainland throughout the zone 5–100 miles from shore. Excluding bays and sewage-contaminated areas, fewer bacteria occur in sediments from the littoral zone than in sediments beyond the littoral zone. This paucity of bacteria in the littoral zone sediments, as well as their abundance in certain oceanic depths, is intimately associated with the physical consistency and organic content of the sedimentary deposits. In general, many more bacteria are found in colloid and clay deposits than in silt or sand. Working in the same region, Trask (1932) found that sand and silt contain much less organic matter than clay or colloidal sediments and that the submarine topography has a greater influence on the median particle size of sediments and their content of organic matter than the depth of the water or the distance from shore. For a consideration of the factors which influence marine sedimentation and the organic content of bottom deposits, the reader is referred to Trask's (1932) report on the *Origin and Environment of Source Sediments of Petroleum.*

The lack of uniformity in the distribution of bacteria in limited areas adds to the complexity of the problem. For example, 0.10 gram of mud dissected from a core has been found to contain several thousand times as many bacteria as a similar portion dissected from the same core 2–3 centimeters away horizontally. This is believed to be due to the unevenness in the distribution of nutrient particles and the tendency of bacteria to colonize. It emphasizes the exigency of fairly large and well mixed samples. It is impracticable to procure sub-samples weighing more than 4–6 grams because, owing to the small diameter of the cores, larger samples are likely to represent more than a single layer or zone. Samples of this size, however, are satisfactory for studying the vertical distribution of bacteria in the sediments.

The upper 3–5 centimeters of the bottom sediment contains the most abundant bacterial population in the sea. Due to the difficulties of obtaining delimited samples of this semi-fluid material, it has been impossible to follow stratification therein, but indications are that the upper millimeter of the colloid-rich ooze is the zone of maximum bacterial activity. Here is where settling organic matter is being deposited and where oxygen may be readily absorbed from the overlying water. Below the first 5 centimeters, where firm cores are obtain-

able, the number of bacteria, anaerobes as well as aerobes, decreases sharply with depth. This is shown in Table II which presents the data from several typical cores from the Channel Island region off southern California. The last six cores described in the table all came from the same basin and they may be considered as duplicate samples. The samples consisted primarily of clay.

TABLE II

NUMBER OF ANAEROBIC AND AEROBIC BACTERIA PER GRAM (WET BASIS) OF SEDIMENTS FROM CORE STRATA OF DIFFERENT DEPTHS. THE DEPTH OF THE WATER AT EACH STATION IS ALSO GIVEN

Sample No.	*Station No.**	*Water Depth in Meters*	*Depth of Core Strata in Centimeters*	*Bacteria per Gram*	
				Anaerobes	*Aerobes*
9,344	35H6	1,215	0– 5	—	35,200,000
			18–20	14,000	10,900
			36–38	1,400	1,600
9,359	35H7	1,044	0– 5	680,000	8,500,000
			20–22	52,000	1,080,000
			41–43	57,000	27,100
9,434	35N5	1,862	0– 2	4,200,000	57,000,000
			24–26	—	189,000
			44–46	8,300	41,200
9,435	35N6	1,952	0– 2	4,250,000	40,900,000
			28–30	17,000	66,000
			52–54	9,500	500
9,436	35N7	1,961	0– 2	9,750,000	38,000,000
			24–26	—	82,000
			43–45	61,000	3,300
9,437	35N8	1,861	0– 2	8,500,000	33,100,000
			23–25	1,600	500
			48–50	9,000	22,400
9,439	35N9	2,007	0– 4	5,200,000	18,800,000
			20–22	—	15,000
			38–40	14,000	8,700
9,449	35N10	1,962	0– 4	1,360,000	16,400,000
			24–26	—	93,000
			46–48	6,000	1,400

* Location, Station No. 35H6 — 33°10.0′N. and 118°27.5′ W., Station No. 35H7 — 33°14.7′ N. and 118°22.5′ W, and Stations Nos. 35N5-10 were all within a one-mile radius from 32°38′ N. and 118°08′ W.

Many irregularities were encountered but, in general, aerobes predominated throughout the core, although in some of the subsurface strata there were more anaerobes than aerobes. The ability to develop in the presence or in the absence of atmospheric oxygen is used as the criterion of aerobes or anaerobes respectively. The latter were cultured in anaerobe jars from which the oxygen was depleted

with yellow phosphorus. A leuco-methylene blue solution was enclosed in the jar as an indicator of anaerobiosis, this solution being oxidized to the colored form by traces of free oxygen. Cognizance is taken of the fact that many of the bacteria are facultative anaerobes, which are capable of developing either aerobically or anaerobically. Such facultative organisms will be counted as aerobes and also as anaerobes. It has not been feasible to estimate their relative abundance. The recovery of large numbers of bacteria which develop aerobically from deep strata which contain no free oxygen would seem to indicate that either these bacteria are passive inhabitants imprisoned by sedimentation or else they are facultative anaerobes.

The sediments when mixed with sea water of known oxygen content were found to absorb from 0.2 to 4.8 milligrams oxygen per gram of dry mud. Six hours was considered as being sufficient time for complete chemical absorption (cf. Moore, 1931), though biological oxygen absorption continued at a slower rate almost indefinitely. The fact that the sediments absorb oxygen chemically indicates that there is no free oxygen present in the interstitial water. Biological absorption of oxygen is attributed primarily to the activity of bacteria; in fact, preliminary experiments indicate that the amount of oxygen absorbed is related to the quantity and kind of organic matter present.

The oxygen-absorbing capacity (both chemical and biological) of the surface layers of mud is much greater than that of mud from deeper layers. Table III gives the oxygen-absorbing capacity of different parts of a 68-centimeter core consisting primarily of fine silt and clay. The number of anaerobes and aerobes, the ratio of anaerobes to aerobes, and the oxidation-reduction potential of corresponding strata are also given. The decrease in oxidation-reduction potential, from -0.12 volt in surface layers to -0.34 volt in deeper layers, indicates that the state of reduction of the sediments increases with depth of burial.

The sample described in Table III was obtained by driving a long pipe, the lower end of which was lined with a glass tube, into the mud in lower San Diego Bay. The ends of the glass tube receiving the sample were stoppered, thereby preventing the entrance of oxygen. Immediately it was taken to the laboratory for analysis. The desired strata were obtained by breaking the tube into sections with a hot-wire cutter and dissecting out uncontaminated central portions of the core.

It will be observed from Table III that the number of both aerobes and anaerobes decreases with the depth of the core, the greatest diminution occurring in the first few centimeters of surface mud. Since

there is a greater decrease in the aerobic than in the anaerobic population, the ratio of anaerobes to aerobes increases with depth. The ratio becomes fairly constant below the first 15 centimeters of mud. The oxygen-absorbing capacity of the mud falls off greatly within the first 5 or 6 centimeters, below which the magnitude of the change is barely greater than the probable experimental error. Although the reducing *capacity* of the mud as indicated by oxygen absorption decreases with depth, measurement of the oxidation-reduction potential reveals that the reducing *intensity* of the sediment increases with depth. The oxidation-reduction potential (cf. Michaelis, 1930) was determined electrometrically, using a saturated *KCl* calomel half-cell connected with a sample of freshly collected mud in which was

TABLE III

THE NUMBER OF ANAEROBES AND AEROBES PER GRAM OF MUD IN STRATA OF DIFFERENT DEPTHS FROM A 68-CENTIMETER CORE TAKEN IN LOWER SAN DIEGO BAY, THE RATIO OF ANAEROBES TO AEROBES, THE MILLIGRAMS OF OXYGEN ABSORBED PER GRAM OF MUD, AND THE OXIDATION-REDUCTION POTENTIAL EXPRESSED AS E_h IN TERMS OF VOLTS

Depth of Strata in Centimeters	*Anaerobes per Gram*	*Aerobes per Gram*	*Ratio of Anaerobes to Aerobes*	*Oxygen Absorbed per Milligram*	*Oxidation-Reduction Potential, E_h in Volts*
0– 3	1,160,000	74,000,000	1:64	2.8	−0.12
4– 6	14,000	314,000	1:21	1.3	−0.29
14–16	8,900	56,000	1:6	0.6	−0.37
24–26	3,100	10,400	1:3	0.7	−0.32
44–46	5,700	28,100	1:5	0.3	−0.37
66–68	2,300	4,200	1:2	0.4	−0.34

submerged a platinum electrode connected to the potentiometer galvanometer circuit. The data submitted have been corrected to the standard normal hydrogen electrode by adding to the observed E.M.F. the values of the saturated calomel electrode found by interpolation from the tables given by Clark (1928). A more complete account of this work will appear in another paper.

All evidence seems to indicate that bacteria are the chief agents which influence the oxidation-reduction potential (intensity and capacity factors) of marine sediments and these potentials in turn effect certain geological, chemical and biological processes, including nitrification, denitrification and other oxidative or reductive reactions. Hewitt (1933) has shown that the normal reducing activities of aerobes range from E_h+0.4 to −0.2 volt and for anaerobes from E_h+0.05 to −0.4 volt. Many bacteria have been recovered from marine sediments which produce hydrogen overvoltages, or oxidation-reduction potentials which are more reducing than E_h−0.421 volt,

the theoretical value of the normal hydrogen electrode. All of the 68 mud samples on which the oxidation-reduction potential has been estimated show negative E_h values, whereas the overlying water always yields positive E_h values. The location of the junction of the positive and negative E_h values has not been ascertained, but it is probably in the mobile layer of colloid-rich material, or it may lie a few millimeters above in the overlying water or below in the underlying mud, the boundaries depending primarily upon the availability of oxygen and organic matter. The difficulties of obtaining delimited samples of material from this zone and the slight poising effect of sea water complicate the problem.

By using differential media, the relative abundance of several important physiological groups has been estimated. Approximately $\frac{1}{4}$ of the bacteria isolated from sediments are proteolytic, as indicated by their ability to liberate ammonium or hydrogen sulphide from proteinaceous materials, or to liquefy gelatin. In most mud samples 5–15 per cent of the bacteria are capable of reducing nitrates to nitrites, but few of them liberate nitrogen from nitrates or nitrites. Special attention has been devoted to nitrifiers, and while they are recovered with regularity from certain areas, they seem to be lacking in other areas. When present, nitrifiers occur only on the top of the cores. Other biochemical processes activated by bottom-dwelling bacteria are urea fermentation, sulphate reduction, cellulose decomposition, agar liquefaction, chitin digestion, and methane production. One or more representatives of these groups occur in most 0.01 gram portions of surface mud and in most 1.0 gram portions of mud from deeper layers. The occurrence of lipolytic species which hydrolyze fats and oils may be of special significance. Such bacteria are readily demonstrated in marine sediments. They assimilate the glycerol from the lipins, but it is not known whether they attack the fatty acids.

Lloyd (1931) has commented on the physiological inertness of bacteria from the Clyde Sea area as manifested by their inability to ferment simple carbohydrates. The bottom-dwelling micro-organisms we have observed may be similarly characterized. Lactose-fermenting organisms have been found in only one mud sample out of 42 which were collected from stations remote from possibilities of terrigenous contamination. Glucose fermenters were more abundant, but less than one per cent of the bacteria produce acid from glucose and a smaller percentage produce gas. Xylose- and arabinose-fermenting bacteria occur in most sediment samples. An astonishingly large number of the bacteria hydrolyze starch, approximately from $\frac{1}{4}$ to $\frac{1}{2}$ of the viable bacteria having this power.

Some of the physiological groups exhibited a semblance of selective stratification throughout the cores, but due to the lack of uniformity in their distribution, generalizations are not yet warranted. It is particularly difficult to estimate the number and kinds of bacteria living in the deeper core strata that activate specific biochemical processes, because there are relatively few bacteria per unit of mud, thus necessitating the use of large samples, and many of the bacteria from the deeper strata multiply very slowly.

One striking difference between the bacteria in the upper layers and those in the deeper layers is the long lag phase preceding the development of the latter and their slow multiplication as contrasted with the more rapid proliferation of the bacteria from the surface slime. Even after prolonged incubation the colonies on plates inoculated with mud from the deeper layers are predominantly of the pinpoint variety, whereas surface sediment colonies are characteristically much larger and require a shorter incubation period for the plate counts to approach constancy.

The majority of the bacteria from the surface slime are obligate halophiles requiring sea-water media for their multiplication. They are very sensitive to lowered concentration of salt either in nutrient media or in dilution waters. Conversely, those from deeper strata are less sensitive to salt content as shown by their ability to grow on either sea-water or fresh-water media and to survive for relatively long periods of time when suspended in waters which are less saline than sea water.

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ROCK TEMPERATURES AND DEPTHS TO NORMAL BOILING POINT OF WATER IN THE UNITED STATES[1]

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ABSTRACT

A table has been prepared showing the highest and lowest extrapolated temperatures in the earth at two given depths for a number of localities. Computed maximum and minimum depths to 212°F. are also given for each locality.

The accompanying table is based on the data tabulated in a recent paper by C. E. Van Orstrand.[3] It gives computed temperatures for depths of 5,000 and 10,000 feet and also gives the depths to the normal boiling point of water (212°F.). The computed temperatures are tabulated in degrees Fahrenheit; the depths in feet.

The results in Van Orstrand's[4] table are grouped so that all of the data for a general locality are listed under one name. In some instances a locality is represented by only a single set of data. The quantities in this table which were used in the computation of the accompanying table by the writer are: a, the computed annual mean temperature just beneath the surface of the earth in degrees F., and b, the geothermal gradient in degrees F. per foot. These quantities are the constants in the straight-line equation,

$$y = a + bx$$

which have been obtained for each location given in the table by making a least-squares adjustment of the straight line to all of the observations in a well.

From a group of results available for each location, two sets of the constants a and b were selected: the one set gives computed maximum temperatures; the other computed minimum temperatures at depths of 5,000 and 10,000 feet from the surface. The same constants are used also to compute the minimum and maximum depths to 212°F. Locations with only a single set of data are included in the table under maximum values. The values of a and b thus selected are given in the table in the columns headed constants. Substitution of

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[2] United States Geological Survey.

[3] C. E. Van Orstrand, "Temperature Gradients," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 980–1021.

[4] *Ibid.*

COMPUTED MAXIMUM AND MINIMUM TEMPERATURES AND COMPUTED DEPTHS TO 212°F.

Location	Single and Maximum Values						Minimum Values					
	Total Depth, Feet	Constants		Computed			Total Depth, Feet	Constants		Computed		
		a	b	Temp. °F.		Depth to 212°F., Feet		a	b	Temp. °F.		Depth to 212°F., Feet
				5,000 Feet	10,000 Feet					5,000 Feet	10,000 Feet	
ALABAMA												
Albany	2,000	61.04	0.00398	81	101	37,900						
Birmingham	1,000	60.08	.01124	116	172	13,500	2,000	59.89	0.00955	108	155	15,900
Fayette	1,250	60.29	.00832	102	143	18,200						
Vernon	3,500	61.26	.00952	109	156	15,800						
ARKANSAS												
El Dorado	2,098	60.66	0.02389	180	300	6,300	2,120	63.93	0.01891	158	253	7,800
CALIFORNIA												
Alamitos Heights	4,000	72.12	0.02277	186	300	6,100	4,000	75.53	0.02043	178	280	6,700
Bakersfield	2,850	70.00	.01666	153	237	8,500	1,450	70.87	.01269	134	198	11,100
Coalinga	1,500	70.31	.02121	176	282	6,700	1,370	71.99	.01351	140	207	10,400
Fullerton	4,270	72.78	.01919	169	265	7,300						
Grass Valley*	3,400	54.63	.00527	81	107	29,900						
Huntington Beach	4,000	66.54	0.02705	202	337	5,400	1,000	68.49	0.02503	194	319	5,700
Kettleman Hills	1,190	70.55	.02052	173	276	6,900	1,350	72.17	.01671	156	239	8,400
Long Beach	3,000	70.85	.02001	171	271	7,100	2,650	72.53	.01726	159	245	8,100
Santa Fe Springs	2,800	66.87	.02265	180	293	6,400	2,175	70.86	.01786	160	249	7,900
Seal Beach	3,500	66.68	.02256	179	292	6,400						
Whittier	2,800	69.84	0.01932	166	263	7,400	3,500	72.62	0.01842	165	257	7,600
COLORADO												
Calhan	4,000	50.10	0.01712	136	221	9,500						
Florence	3,500	54.28	.02151	162	269	7,300	2,900	54.24	.02020	155	256	7,800
Fort Collins	4,000	50.41	.01956	148	246	8,300	3,000	50.58	.01861	144	237	8,700
Longmont	6,500	50.74	.02399	171	291	6,700						

* W. D. Johnston, Jr., "Geothermal Gradient at Grass Valley, California," *Jour. Washington Acad. Sci.*, Vol. 22 (May 19, 1932), pp. 267–71 (August 19, 1932), pp. 390–93. Adolph Knopf, "Geothermal Gradient of the Mother Lode Belt, California" *Ibid.*, Vol. 22 (August 19, 1932), pp. 389–90.

COMPUTED MAXIMUM AND MINIMUM TEMPERATURES AND COMPUTED DEPTHS TO 212°F. (*Continued*)

Location	*Single and Maximum Values*						*Minimum Values*					
	Total Depth, Feet	Constants		Computed			Total Depth, Feet	Constants		Computed		
		a	b	Temp. °F.		Depth to 212°F., Feet		a	b	Temp. °F.		Depth to 212°F., Feet
				5,000 Feet	10,000 Feet					5,000 Feet	10,000 Feet	
ILLINOIS												
Bridgeport	1,800	54.88	0.01725	141	227	9,100	1,250	56.80	0.01526	133	209	10,200
IOWA												
Ames†	2,100	49.70	0.00710	85	121	22,900						
KANSAS												
Augusta	2,250	59.45	0.01984	159	258	7,700	2,250	58.32	0.01908	154	249	8,100
Eldorado	2,250	56.73	.02096	162	266	7,400	2,250	56.22	.01741	143	230	8,900
Florence	2,150	56.87	.01647	139	222	9,400	1,500	57.51	.01566	136	214	9,900
Haverhill	2,250	57.25	.01936	154	251	8,000	2,750	58.52	.01783	148	237	8,600
Syracuse‡	4,600	55.00	.01428	126	198	11,000						
KENTUCKY												
Prater Creek	1,500	57.61	0.00637	89	121	24,200						
Rockcastle Creek	1,500	54.98	.00764	93	131	20,600						
LOUISIANA												
Blue Lake	2,000	65.79	0.02250	178	291	6,500	1,500	67.54	0.01993	167	267	7,200
Caddo Lake	2,000	65.83	.02423	187	308	6,000	3,500	69.13	.02218	180	291	6,400
Haynesville	2,750	64.41	.02245	177	289	6,600						
Homer	2,000	65.48	.03049	218	370	4,800	1,150	62.11	.02646	194	327	5,700
Many	2,440	61.59	.02451	184	307	6,100	1,250	64.41	.01926	161	257	7,700
Monroe	2,250	63.11	0.02357	181	299	6,300	1,500	62.94	0.02115	169	274	7,000
Sligo	750	64.84	.02639	197	329	5,600	1,650	66.23	.02318	182	298	6,300
Zwolle	3,380	69.03	.02191	179	288	6,500	1,250	66.01	.01771	155	243	8,200
MICHIGAN												
Houghton§	6,250	36.29	0.00922	82	128	19,100	1,654	41.40	0.00784	81	120	21,800
Lake Linden	1,435	43.15	.00757	81	119	22,300						
Surrey Township	3,700	40.14	.01887	134	229	9,100						

† W. S. Beyer, *The Iowa Agricultural College Water Supply* (Ames, May, 1897).
‡ N. W. Bass, *Kansas State Geol. Survey Bull. 11* (1926), p. 83.
§ From 4,815 to 6,250 feet.

MISSISSIPPI												
Amory††	2,000	60.62	0.00813	101	142	18,600						
Jackson††	2,250	66.65	.02867	210	353	5,100	2,250	66.84	.02537	194	321	5,700
MONTANA												
Anaconda‖	1,600	42.61	0.02111	148	254	8,000						
Kevin-Sunburst	1,250	47.25	.01712	133	218	9,600	3,000	47.46	.00877	91	135	18,800
NEVADA												
Virginia City¶	2,300	50.86	0.03105	206	361	5,200						
NEW JERSEY												
Franklin Furnace**	2,500	50.80	0.00585	80	109	27,600						
NEW MEXICO												
Artesia	1,500	67.13	0.00611	98	128	23,700	2,892	68.86	0.00439	91	113	32,600
Carlsbad	2,874	67.75	.00578	97	126	25,000						
Lovington	4,500	68.01	.00554	96	123	26,000						
Roswell	3,000	65.50	.00583	95	124	25,100	2,950	65.67	.00576	94	123	25,400
NEW YORK												
Greenwood Township††	4,250	45.39	0.01608	126	206	10,400						
Tyrone††	1,750	47.39	.01907	143	238	8,600						
Willing Township††	4,700	41.32	.01697	126	211	10,100						
NORTH DAKOTA												
Lonetree	3,750	40.00	0.01998	140	240	8,600						
OKLAHOMA												
Ardmore	3,000	62.53	0.00978	111	160	15,300	1,500	63.24	0.00678	97	131	21,900
Ardmore-Healdton	1,000	63.18	.01265	126	190	11,800	1,500	62.29	.00657	95	128	22,800
Ardmore-Hewett	1,000	60.47	.01152	118	176	13,200	1,750	63.48	.00764	102	140	19,400
Bessie	1,500	62.89	.00828	104	146	18,000						
Billings	3,500	60.15	.01911	156	251	7,900	650	62.57	.01708	148	233	8,700
Blackwell	1,835	56.61	0.02111	162	268	7,400	2,000	58.06	0.02027	159	261	7,600
Braman	1,375	54.89	.02313	171	286	6,800	1,410	59.34	.01829	151	242	8,300
Burbank	2,850	57.34	.02188	167	276	7,100	2,750	59.70	.02087	164	268	7,300
Covington	1,600	61.50	.01933	158	255	7,800						
Cromwell	2,750	59.02	.02203	169	279	6,900	1,200	59.94	.01918	156	252	7,900

†† Recent observations by C. E. Van Orstrand.
‖ N. H. Darton, "Geothermal Data of the United States," *U. S. Geol. Survey Bull. 701* (1920), pp. 58–59.
¶ G. F. Becker, "Geology of the Comstock Lode and the Washoe District," *U. S. Geol. Survey Mon. 3* (1882), pp. 246–52.
** From 625 to 2,500 feet.

COMPUTED MAXIMUM AND MINIMUM TEMPERATURES AND COMPUTED DEPTHS TO 212°F. (*Continued*)

Location	*Single and Maximum Values*						*Minimum Values*					
		Constants		*Computed*				*Constants*		*Computed*		
	Total Depth, Feet	*a*	*b*	*Temp. °F.*		*Depth to 212°F., Feet*	*Total Depth, Feet*	*a*	*b*	*Temp. °F.*		*Depth to 212°F., Feet*
				5,000 Feet	*10,000 Feet*					*5,000 Feet*	*10,000 Feet*	
OKLAHOMA (*Continued*)												
Davenport	3,375	58.67	0.01162	117	175	13,200						
Dilworth	1,766	59.38	.02082	163	268	7,300	3,000	58.70	.01874	152	246	8,200
Drumright	2,250	55.21	.02074	159	263	7,600	2,000	60.41	.01328	127	193	11,400
Glenn Pool	1,670	59.08	.02743	196	333	5,600	1,250	62.95	.02008	163	264	7,400
Holdenville‡‡	5,200	61.38	.02002	161	262	7,500						
Hubbard	2,870	60.29	0.02103	165	271	7,200						
Morris	1,610	61.24	.02454	184	307	6,100						
Newkirk	3,000	59.52	.02224	171	282	6,900						
Okemah	2,500	59.60	.02549	187	315	6,000	2,750	60.58	.02313	176	292	6,500
Oklahoma City	4,000	59.04	.00973	108	156	15,700	4,000	60.02	.00933	107	153	16,300
Papoose	2,750	59.24	0.02367	178	296	6,500	2,500	64.67	0.02014	165	266	7,300
Perry	3,000	58.96	.01717	145	231	8,900						
Sasakwa	3,500	60.08	.01878	154	248	8,100	2,620	59.05	.01518	135	211	10,100
Seminole	3,250	59.58	.01801	150	240	8,400	2,000	63.38	.01240	125	187	12,000
Tonkawa	4,000	59.97	.02031	162	263	7,500	2,000	62.61	.01809	153	244	8,300
Walters	1,570	63.26	0.00905	109	154	16,400	2,000	63.53	0.00822	105	146	18,100
Wewoka	3,000	60.16	.02107	166	271	7,200	2,160	60.77	.02046	163	265	7,400
OREGON												
Astoria	3,780	51.07	0.01670	135	218	9,600						
Burns	300	52.03	.05850	345	637	2,700						
Klamath Falls	375	46.89	.06031	348	650	2,700	500	49.63	.00730	86	123	22,200
Medford	725	56.81	.01641	139	221	9,500	899	58.64	.01320	125	191	11,600
Merrill	660	50.47	.02471	174	298	6,500						
Vale	1,295	59.84	0.04575	289	517	3,300						

‡‡ H. D. Miser, "Temperature of Oklahoma's Deepest Well," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (July–August, 1924), pp. 525–26.

PENNSYLVANIA												
Gaines Junction	5,500	41.04	0.01619	122	203	10,600						
Genesee Township††	5,000	41.16	.01638	123	205	10,400						
Hebron Township††	5,250	38.92	.01700	124	209	10,200						
Johnstown	6,500	42.70	.01313	108	174	12,900						
Long Bridge	6,500	45.12	.01674	129	213	10,000	6,815	46.88	.01565	125	203	10,600
McDonald	6,975	48.09	0.01444	120	192	11,400						
McKeesport	3,250	51.54	.01268	115	178	12,700						
TEXAS												
Bastrop	2,000	74.35	0.02110	180	285	6,500						
Big Lake	2,725	67.59	.00730	104	141	19,800	2,975	68.36	.00587	98	127	24,500
Blue Ridge	700	69.75	.02677	204	337	5,300	2,500	72.62	.01717	158	244	8,100
Boggy Creek	3,679	63.05	.03013	214	364	4,900	3,590	72.88	.02333	190	306	6,000
Bonham	1,140	66.26	.02186	176	285	6,700						
Callisburg	3,680	64.14	0.00982	113	162	15,100						
Canadian	4,758	60.58	.01001	111	161	15,100						
Dale	2,250	68.36	.02299	183	298	6,200						
Damon	4,000	71.64	.01619	153	234	8,700						
Del Rio	3,686	74.11	.01311	140	205	10,500						
DeWitt County	1,970	70.88	0.01902	166	261	7,400						
Dickens County	2,400	65.42	.00877	109	153	16,700						
Eastland County	3,000	65.93	.01885	160	254	7,700						
Edwards	6,600	65.02	.01666	148	232	8,800						
Electra	1,830	65.58	.01224	127	188	12,000						
Ennis	1,325	70.08	0.01856	163	256	7,600						
Ferris	1,250	66.55	.02024	168	269	7,200						
Graford	3,000	67.32	.01856	160	253	7,800						
Graham	4,334	66.36	.01732	153	240	8,400	3,000	71.16	.01638	153	235	8,600
Grand Saline	715	65.85	.02140	173	280	6,800	875	69.07	.01606	149	230	8,900
Greenville	1,750	67.13	0.01855	160	253	7,800						
Guthrie	2,950	66.40	.00898	111	156	16,200						
Humble	1,080	65.73	.04517	292	517	3,200	2,000	67.03	.01677	151	235	8,600
Independent	525	68.98	.00927	115	162	15,400						
Leonard	2,500	67.85	.01487	142	217	9,700						
Long Point	857	70.18	0.03715	256	442	3,800	3,300	71.68	0.01765	160	248	8,000

COMPUTED MAXIMUM AND MINIMUM TEMPERATURES AND COMPUTED DEPTHS TO 212°F. (*Continued*)

Location	*Single and Maximum Values*						*Minimum Values*					
	Total Depth, Feet	*Constants*		*Computed*			*Total Depth, Feet*	*Constants*		*Computed*		
				Temp. °F.		*Depth to 212°F., Feet*				*Temp. °F.*		*Depth to 212°F., Feet*
		a	*b*	*5,000 Feet*	*10,000 Feet*			*a*	*b*	*5,000 Feet*	*10,000 Feet*	
TEXAS (*Continued*)												
Luling	1,000	70.68	.02285	185	299	6,200	2,500	76.41	.01886	171	265	7,200
Lytton Springs	1,175	69.97	.02559	198	326	5,600	1,350	70.79	.02297	186	300	6,100
Mexia	2,985	65.43	.02393	185	305	6,100	3,000	68.15	.02016	169	270	7,100
Muenster	1,500	60.23	.01454	133	206	10,400						
Odessa	1,985	67.93	0.00717	104	140	20,100						
Ozona	5,500	60.18	.01624	141	223	9,300						
Panhandle Area	1,975	62.42	.01070	116	169	14,000	3,440	61.18	.00552	89	116	27,300
Pierce Junction	3,300	72.50	.01753	160	248	8,000	4,303	83.19	.01486	157	232	8,700
Powell	2,710	66.14	.02278	180	294	6,400	2,950	91.29	.01460	164	237	8,300
Ranger	3,000	65.88	0.02237	178	290	6,500	3,000	65.38	0.02067	169	272	7,100
Rosewood	1,500	69.67	.02027	171	272	7,000						
Sherman	730	65.16	.01573	144	222	9,300	1,450	65.38	.01388	135	204	10,600
Saint Jo	1,729	61.13	.01190	121	180	12,700						
Thrifty	1,250	68.78	.01624	150	231	8,800						
Waco	1,070	69.62	0.02161	178	286	6,600	1,990	74.53	0.01734	161	248	7,900
Wolfe City	2,000	63.17	.02020	164	265	7,400	1,700	64.34	.01973	163	262	7,500
Wortham	2,800	75.66	.02069	179	283	6,600	2,900	77.09	.01954	175	272	6,900
WASHINGTON												
Ballard Station	2,500	48.96	0.00949	96	144	17,200						
Benton City	2,200	59.44	.02064	163	266	7,400						
Moclips	3,500	44.37	.01378	113	182	12,200						

WEST VIRGINIA												
Bridgeport	7,310	49.75	0.01401	120	190	11,600						
Fairmont	7,500	49.24	.01521	125	201	10,700						
Grantsville	4,500	52.71	.01204	113	173	13,200						
Mannington	3,225	53.52	.01096	108	163	14,500						
Spencer	6,500	50.85	.01293	116	180	12,500	3,250	53.12	.01179	112	171	13,500
Volcano Junction	4,250	48.99	0.01437	121	193	11,300						
Volcano	4,400	49.02	.01476	123	197	11,000						
West Union	6,500	45.73	.01385	115	184	12,000						
Wheeling‖‖	4,462	47.69	.01349	115	183	12,200						
Wyatt	2,000	53.61	.01018	105	155	15,600						
WYOMING												
Big Muddy	3,000	49.38	0.01963	148	246	8,300	3,000	53.08	0.01707	138	224	9,300
Cody	4,250	51.51	.01698	136	221	9,500	3,250	51.80	.01677	136	220	9,600
Grass Creek	700	47.15	.01981	146	245	8,300	800	46.50	.01934	143	240	8,600
Lance Creek	3,000	49.79	.02779	189	328	5,800	3,000	48.19	.02718	184	320	6,000
Lost Soldier	1,925	47.61	.04895	292	537	3,400	3,400	48.87	.02569	177	306	6,300
Pine Mountain	2,240	49.00	0.02507	174	300	6,500						
Rawlins	1,500	46.11	.02034	148	250	8,200	2,000	43.77	.01708	129	215	9,800
Rock River	2,700	43.87	.01918	140	236	8,800	2,900	47.22	.01330	114	180	12,400
Salt Creek	1,500	48.12	.03483	222	396	4,700	2,650	47.83	.02079	152	256	7,900
Tea Pot	2,736	46.46	.02744	184	321	6,000						
Thermopolis	1,000	50.86	0.04784	290	529	3,400	900	50.95	0.04206	261	472	3,800
Thermopolis (near)	1,407	51.26	.01945	149	246	8,300	3,000	47.26	.01612	128	208	10,200

‖‖ From 1,350 to 4,462 feet.

W. Hallock, "Subterranean Temperatures at Wheeling, West Virginia, and Pittsburgh, Pennsylvania," *School of Mines Quart.*, Vol. 18 (January, 1897), pp. 148–54.

"Underground Temperatures at Great Depths," *Amer. Jour. Sci.*, 4th Ser. Vol. 154 (1897), p. 76.

"Preliminary Report of Observations at the Deep Well, Wheeling, West Virginia," *Amer. Jour. Sci.*, 3rd Ser. Vol. 43 (1892), pp. 234–36.

the constants in the equation of a straight line gives the temperature y in degrees F. at the depth x in feet. For example, highest values of temperature for El Dorado, Arkansas, may be computed by solving for y, when x is greater than 800 feet, in the equation

$$y = 60.66 + 0.02389x$$

In a similar manner lowest values of temperature are computed from

$$y = 63.93 + 0.01891x$$

Depth (x) to 212°F. is computed for maximum values in the same example from

$$212 = 60.66 + 0.02389x,$$

and for minimum values,

$$212 = 63.93 + 0.01891x$$

The errors in the interpolation of depth-temperature curves are probably less than 1°F. in most cases;[5] but the extension of the curves to greater depths may lead to larger errors, as the depth-temperature curves near the surface of the earth are seldom, if ever, straight lines.[6] The extrapolation of a straight line assumed to represent a curve which is concave to the depth axis (abscissa) gives an estimated temperature that is too high; while extrapolation of the convex curve under similar conditions leads to temperatures that are too low. Also, the extrapolation of the curves for which the total depth is small gives an estimate of comparatively less worth than those for which the depth is large.

Temperature gradients are assumed to be high on anticlines and low on synclines. Many observations of temperature have been made in oil fields, most of which are located on anticlines, but few observations have been made in synclines. Since most of the computed temperatures in the table are based on observations in oil fields, it is probable that the maximum and minimum temperatures may be more representative of a maximum and that in structural basins the minimum temperatures would be lower and the depths to 212°F. greater.

Because of the activity of water in geological processes, the depths to the normal boiling-point temperature (212°F.) are of fundamental importance in the discussion of geological phenomena. Van Orstand's[7] early conclusion that the depths to boiling-point temperature are frequently less than 10,000 feet is borne out by this paper. The evidence assembled in the table shows that at approximately one-third of the locations represented, the boiling-point temperature is reached

[5] *Ibid.*, p. 1006.

[6] *Ibid.*, p. 1007.

[7] C. E. Van Orstrand, "Temperature in World's Deepest Well," *Oil and Gas Jour.*, Vol. 26, No. 48 (April 19, 1928), p. 39.

at a computed depth of 7,000 feet or less; and at two-thirds of the localities the depth to this temperature is 10,000 feet or less. Professor Lindgren's[8] recent conclusion that meteoric waters may penetrate to depths of 8,000–10,000 feet, and probably more, is of importance in connection with the preceding results, as is the conclusion of Allen and Day[9] in their paper on thermal activity, that "the temperature gradient is much greater in some localities than the geologists are aware of."

It was pointed out by Van Hise,[10] and later by Lindgren,[11] that high temperatures beneath the surface of the earth may be simply the effect of the natural increase of temperature with depth. They each assumed a gradient of 1°C. for each 30 meters of depth, or the equivalent 1°F. for about 55 feet, and an annual mean temperature at the surface of the earth of 25°C. (77°F.). The critical temperature of water, 365°C. (689°F.), is estimated from these assumptions to be at a depth of 10,200 meters, or about 33,600 feet. Van Orstrand[12] has computed the depth to the critical temperature of water to be 6,765 feet for a reciprocal gradient of 1°F. in 10.4 feet. Extrapolation for a few localities given in the table, to the depth at which a temperature of 689°F. is obtained, gives the following depths.

	Feet
Lost Soldier, Wyoming	13,100
Thermopolis, Wyoming	13,300
Vale, Oregon	13,800
Jackson, Mississippi	21,700
Huntington Beach, California	23,000
Glenn Pool, Oklahoma	23,000
Eldorado, Kansas	30,200
Greenwood Twp., New York	40,000
Oklahoma City, Oklahoma	64,700
Grass Valley, California	120,400

Further extrapolation of the temperature curves which show that temperatures of 212°F. are reached at depths of 7,000 feet or less show that a temperature of 689°F. is reached at depths consistently less than 30,000 feet. Similarly, those curves which show temperatures of 212°F. at depths of 10,000 feet or less show that a temperature of 689°F. is reached at depths that are, with few exceptions, less than 40,000 feet.

[8] Waldemar Lindgren, "Waters, Magmatic and Meteoric," *Econ. Geol.*, Vol. 30, No. 5 (August, 1935), pp. 463–77.

[9] E. T. Allen and A. L. Day, "Steam Wells and Other Thermal Activity at 'The Geysers', California," *Carnegie Inst. of Washington Pub. 378* (1927).

[10] C. R. Van Hise, "A Treatise on Metamorphism," *U. S. Geol. Survey Mon.*, Vol 47 (1904), p. 566.

[11] Waldemar Lindgren, *Mineral Deposits*, McGraw-Hill Book Company, Inc., New York, 4th edition (1933), p. 641.

[12] C. E. Van Orstrand, "Temperatures in Some Springs and Geysers in Yellowstone National Park," *Jour. Geol.*, Vol. 32, No. 3 (April-May, 1924), p. 223.

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ORIGINS OF PETROLEUMS; CHEMICAL AND GEOCHEMICAL ASPECTS[1]

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ABSTRACT

The survival of organic material in oil shales of great geological antiquity is evidence against the assumption that petroleums have been formed by the heat decomposition of organic material. Another evidence of the low-temperature history of oil shale is the discovery of Treibs that many shales, asphalts, and asphaltic petroleums contain chlorophyll porphyrins. The fact that many petroleums contain complex labile substances easily decomposed by heat, may indicate that cellulose, peats, and coals are progressively carbonized under pressure and during geologic time at temperatures much lower than has heretofore been assumed. The carbon-ratio theory has only a negative value in relation to petroleum occurrence.

Some bottom-hole temperatures in producing fields do not exceed 100°F., and are in strata only slightly arched or otherwise disturbed.

The conclusion seems warranted that organic materials as stable as the paraffins and some waxes, once formed and sealed in the sedimentary rocks, normally undergo no further changes due to the influence of heat.

The principal types of organic substances which are to be considered as the main source material for petroleum include cellulose, starches, and sugars, proteins, lignins, oleo-resins, waxes, and fatty oils. Fatty oils are to be regarded as the principal source material.

Putrefactive decomposition of organic matter is recognized as an initial step in the formation of petroleum. More experimental evidence is needed on the rôle of bacteria in the formation of petroleum. At present the depth at which bacterial action ceases is not known.

The low-temperature history of petroleum favors the view that the hardening of sedimentary rocks is due entirely to compaction and the deposition of cementing material from solution.

The earlier theories of the origin of petroleum were proposed when little was known of the chemical character of petroleum and other organic minerals: coal, lignites, kerogen, asphalts, fossil resins, and waxes. Geological knowledge relating to these organic materials was equally fragmentary when the theory of the heat decomposition of fatty oils of marine sources, or as it is often known, the destructive-distillation theory of petroleum origin, was suggested by Warren and Storer (47)[3] in 1863, and later (1888) by Engler (10). Though this theory is still widely held, it has become increasingly difficult for geologists to reconcile it with the evidence of geology. Thus on geological grounds alone Illing (18) has stated that the geological evidence demands a theory of petroleum origin contemporaneous with the

[1] Presented at the Symposium of Organic Chemistry, held by the Organic Division of the American Chemical Society, Rochester, New York, January 1, 1936. Manuscript received, January 16, 1936.

[2] Chemical engineer, 114 East Thirty-Second Street.

[3] See References at end of article.

sediments and "not, as the distillation theory would suppose, as a later process of metamorphism." Beeby Thompson (39) also states:

> In seeking the origin of petroleum one must not introduce extraordinary theories for its occasional occurrence amongst unusual surroundings, but consider only such views as will account for its *extensive production and wide distribution by common processes of nature.*

The current ideas regarding source beds for petroleum have been well reviewed by Snider (31). (See also the articles by P. D. Trask and V. C. Illing in bibliography at end of this article.)

As the physical conditions, particularly low temperatures, have become widely recognized, the heat-decomposition theory has been modified. It is generally believed that the organic material originally deposited in the source sediments must have been solid or semi-solid in order to be held in the original muds and that the conversion to oil came later by the slow action of mild degrees of heat. This view was held by the late David White (50), who believed that the change of coal to higher fixed-carbon ratios was evidence of thermal effect and that the same conditions producing these changes in coals were factors in the production and alteration of petroleums. From a study of the Appalachian coal and oil fields White believed that in regions where the fixed-carbon coal deposits exceeded 60–64 per cent no oil would be found, and he outlined so-called extinction zones where conditions of metamorphosis were believed to preclude the finding of oil. The present status of the carbon-ratio theory has been recently reviewed by Thom (38). Some support for the alteration of petroleum with age and depth, by thermal influence, is to be found in the recent studies of Barton (2) of the oils in the Gulf Coast region, who showed that in this area most of the oils become lighter and more paraffinic with age and depth. However, this relation has been shown not to hold in Wyoming (3) and California fields (34). Although petroleums may have been altered in certain instances by regional metamorphism, it is doubtful, in view of the evidence submitted in the following discussion, if heat has been the primary factor in the formation of petroleums (6).

Consideration of petroleums alone, excluding other organic minerals, would be inadequate, as much of the evidence as to petroleum origin, source materials, and physical conditions prevailing in sedimentary strata, is furnished by other organic material deposited in strata of widely varying geologic age.

COMMON ORGANIC MINERALS

In Cambrian and pre-Cambrian rocks, graphite occurs in some places in the form of small flakes. Some of the pre-Carboniferous

coals approach pure carbon in composition (ash-free basis) and some contain small quantities of graphitic carbon. Graphite deposits may be classified as (1) bedded and disseminated deposits derived from organic matter in sediments by contact or regional metamorphosis and (2) vein deposits formed by igneous intrusions (7,8,25,44).

The formation of petroleum by the heat decomposition of the kerogen of oil shale, or of coal, would presumably leave a carbonized residue, possibly graphitic, if it is assumed that the gas and oil are removed in some way to cooler absorbent strata. However, disseminated graphitic material is geologically far removed and geographically usually very remote from oil-producing strata. Mention is made of the occurrence of disseminated graphite only because the theory that petroleum has been formed by the heat decomposition of something requires an association within reasonable distances of petroleum or natural gas, and graphite or highly carbonized residues.

The relative abundance of petroleum through the geologic scale runs nearly parallel with the abundance of the other organic material and fossil remains. Although the Lima-Indiana petroleum and certain of the deeper Mid-Continent and Texas oils are derived from the Middle Ordovician, organic material is not abundant until much later, in the thick beds of the black shale of the Devonian period. In the more recent Carboniferous period both coal and oil are still abundant, and oil is found scattered through the more recent periods to and including the Tertiary. It is noteworthy that many oil shales, containing kerogen but little or no oil, are geologically much older than many petroleums. Probably the oldest of these shales is the New Brunswick shale, which Ells (9) places at the bottom of the Cambrian series. The oil shales of Esthonia, Ontario, and Ohio are Devonian and those of Scotland, Nova Scotia, New South Wales, and one deposit in Brazil belong to the Carboniferous period. The geological antiquity of many of the oil shales is a striking proof of the chemical stability of the organic material contained in them under conditions of temperatures and pressures prevailing in these beds through their long history. In other words, the survival of such organic material, in many places without the formation of oil, is very satisfactory evidence against the assumption that petroleums have been formed by the heat decomposition of organic material, at least of the kerogen type.

Perhaps the most convincing evidence of the low-temperature history of oil shale, as well as petroleum, is furnished by the recent discovery of Treibs (41) that many shales, asphalts, and asphaltic petroleums contain chlorophyll porphyrins. In a discussion of the origin of oil shales George (13) states that in some of the oil shales

fossil plants predominate and in others fish or animal remains are relatively rich. Treibs found evidence of meso-porphyrin, derived from haemin, in several oil shales, which correponds with the mixed character of the fossil remains. However, in the series of oil shales, asphalts, and petroleums investigated by Treibs, chlorophyll porphyrins predominated and were the only porphyrins detected in most cases.

Very little is known of the chemical nature of kerogen (24). Extraction of oil shales with solvents usually yields very little oil, for example, New Brunswick shale yields 1.36 per cent of the shale or about 4 per cent of the kerogen, by extraction with various solvents (12). Only traces of the extracted material distill below 200°C., showing the complete absence of oils of the nature of gasoline. The carbon-hydrogen ratio of kerogen in various oil shales varies from about 7.42 to 8.92. The nitrogen appears largely as ammonia, on destructive distillation, and the sulphur content is often high, forming hydrogen sulphide and a series of complex organic derivatives.

TABLE I

CONSTITUENTS OF CANNEL-COAL DISTILLATES

	Carbonic Acids, Per Cent	*Phenols, Per Cent*	*Organic Bases, Per Cent*
1	0.04	1.70	2.02
2	0.20	1.30	1.30
3	0.14	2.35	1.68
4	0.20	3.42	1.85
5	0.50	2.00	2.00
6	0.44	1.70	0.30

The kerogen of oil shales, in its insolubility in solvents and in the character of the products obtained on destructive distillation, closely resembles the cannel or bog-head coals. Stadnikoff (32) has recently published a great deal of evidence to show that the organic material in cannel and bog-head coals consists almost wholly of products of polymerization and anhydride formation of fatty acids. The oils obtained by destructive distillation contain only very small amounts of phenols, are rich in olefins, the lighter distillates contain free fatty acids, and the higher boiling fractions contain small proportions of saponifiable material, yielding fatty acids after saponification, which Stadnikoff regards as fatty acid anhydrides. The oxygen content of these oils also indicates the presence of neutral oxygen derivatives, probably ketones. The gas formed is mainly methane.

Stadnikoff gives the composition of the oil distillates of several cannel-type coals in Table I.

Brown coals, though chemically quite different from cannel coals and oil shales, commonly contain resin and wax, the survival of which through long geological periods is striking proof of the low-temperature conditions prevailing since their deposition. Resin inclusions, resembling kauri gum, have been found in New Zealand brown coal (19). The resin was found to consist almost completely of a carboxylic acid. Still more striking is the survival of organic esters of the higher alcohols, as in montan wax of German brown coals. This wax contains the acids (42) carboceric, $C_{27}H_{54}O_2$, and montanic, $C_{29}H_{58}O_2$, and as esters the alcohols tetracosanol, $C_{24}H_{50}O$, ceryl alochol, $C_{26}H_{54}O$, and myrcil alcohol, $C_{30}H_{62}O$. The amorphous, rather indefinite mineral, pyropissite, occurring in Tertiary brown coals, begins to give off gas and decomposition products on heating to 120°–150°C. and on destructive distillation yields a mixture of crystalline paraffins, saturated and olefinic oils.

It has long been believed that the progressive carbonization of coals has been primarily due to heat, or to heat and pressure. Thom (38) concludes that fixed-carbon ratios of coal appear to provide a fair qualitative index of local metamorphic intensity. Regions containing anthracite coals are apparently completely barren of commercial oil pools. Thom also states that carbon ratios do not afford sufficiently accurate or critical evidence to warrant the drawing of "dead-line" limits to possible oil and gas occurrence. He regards coals as "particularly sensitive" to the influence of heat and pressure. The fact that many petroleums contain complex labile substances easily decomposed by heat, may indicate that cellulose, peats, and coals are progressively carbonized under pressure and during geologic time at temperatures much lower than has heretofore been assumed. Thom states,

> The assumption that oil is generated *only* by dynamo-chemical alteration of organic source materials is contradicted by what is now known of the occurrence of oil in relatively young formations. . . . A great proportion of the world's known oil fields of importance occur in sedimentary rocks which are entirely or almost wholly unconsolidated, and the remaining fields occur in formations which are unmetamorphosed and only partially filled with cementing materials.

In other words, the carbonization of coal, serving as a "qualitative index of local metamorphic intensity" may indicate conditions severe enough to have destroyed petroleum, but can not be accepted as evidence for the manner of petroleum formation under the very different conditions of the normal occurrences of petroleum.

It has often been assumed that the hardening of sedimentary strata, or lithification, has been mainly due to pressure and tempera-

ture. Compaction by pressure is evident and is generally progressive with the depth (26). But, in view of the very low-temperature history of petroleum which the chemical evidence indicates, it is much more probable that cementation by deposition of the cementing material from solution, together with compaction, are the primary factors.

Ozokerite is generally believed to occur as a mechanical concentration or separation of the higher melting, less soluble paraffins of petroleum. It is of interest in this connection only as indicating that the conditions of temperature and pressure of the deposits in which it is found have not been sufficient to change it to mixtures resembling petroleum. The occurrence of ozokerite is an indication that petroleums are not so-called equilibrium mixtures of hydrocarbons produced by heat, and that such hydrocarbons, once formed, may be separated, filtered, and absorbed and concentrated but not chemically changed by natural conditions.

NATURAL GAS

Methane, though now known to be a major constituent of the atmospheres of some of the planets (29), and known to be formed from certain metallic carbides by the action of water, is also formed by the common anaerobic fermentation of cellulose. The composition of natural gas accompanying petroleum has a definite bearing on the genesis of petroleum. Natural gas contains no trace of hydrogen, carbon monoxide, or ethylene; gas formed by the pyrolysis of fatty acids or natural fats, as in Engler's experiments, contains all three of these substances. Although ethylene and carbon monoxide can be hydrogenated under suitable conditions and in the presence of specially prepared catalysts, it is not reasonable to assume that these three substances would always be produced by pyrolysis in exactly the proportions required for their subsequent complete elimination by hydrogenation. The absence of hydrogen in natural gas accompanying petroleum is also very strong evidence against the theory, suggested by S. C. Lind (21), that petroleum has been formed by the action of alpha radiation from radioactive minerals on methane, since hydrogen is formed in large proportions from methane in the process.

The occurrence of helium in small proportions in natural gas in certain localities, in the light of the evidence of organic origin, is to be regarded as an adventitious constituent probably derived from primitive granites beneath the sedimentary rocks, as in the case of the old buried granite ridges in the Mid-Continent area of the United States or from secondary radioactive minerals as in the Shinarump conglomerate of Colorado.

NATURAL OCCURRENCES OF HYDROCARBONS

In connection with Beeby Thompson's (39) statement regarding "common processes of nature," it should be noted that saturated paraffins and olefinic hydrocarbons of widely varying types are found in nature, produced by biochemical processes at ordinary temperatures. At least fifteen normal paraffin waxes occur in the essential oils of about twenty-five plant species, as in the oil of roses, the buds of the sweet birch, tobacco, et cetera. The source of pure normal heptane, used as a standard reference fuel in the determination of knock rating, is produced by two pines in the western United States, *Pinus sabiniana* and *P. Jeffreyi*, and also by a prune-like fruit in the Philippine Islands. The chemical mechanism by which such paraffins are formed in growing plants is quite unknown, and though it is obvious that petroleum has not been formed by accumulations of hydrocarbons from such sources, their natural occurrence is important as showing that "the processes of nature" can produce them at normal temperatures. The natural paraffins are not associated with fatty acids of the same or C_nH_{2n+1} carbon atoms, and many contain more carbon atoms than any known fatty acid.

The terpenes, $C_{10}H_{16}$, the sesquiterpenes, $C_{15}H_{24}$, and the rubber hydrocarbons, rather widely distributed in nature, appear to be related to the C_5 group of the pentoses and the pentosans, from which they may be derived by biochemical processes of dehydration and reduction (or biochemical hydrogenation).

It is not at all necessary to assume that a high energy input is necessary to accomplish such reductions. Such results are observed to occur with very little net energy change by the conversion of part of the original material to an oxidized state and part to a reduction product, as in the conversion of sugar or glucose to carbon dioxide and ethyl alcohol, and the fermentation of cellulose to methane, carbon dioxide, and small proportions of other products. One of the significant corollaries of the discovery of chlorophyll porphyrins in petroleums, asphalts, and oil shales is that the original organic material associated with these porphyrins rather quickly passed into an anaerobic environment, since chlorophyll is rapidly destroyed in aerobic fermentations. It is possible that anaerobic fermentations will be discovered which will produce ethane, propane and other hydrocarbons.

COMPOSITION OF PETROLEUMS

Our knowledge of the composition of petroleums is now much more extensive than when the theory of heat decomposition was first

suggested. The facts as to composition which have a bearing on the question of petroleum origin may be briefly stated.

The relative proportions of paraffins, naphthenes, and benzenoid hydrocarbons, wax, and asphalt in petroleums are summarized by Stadnikoff (32) in Table II.

TABLE II

AVERAGE COMPOSITION OF TYPICAL PETROLEUMS

Type of Crude	*Wax, Per Cent*	*Asphalt, Per Cent*	*Composition of 250°–300°C. Fraction*			*Specific Gravity of Residue over 300°C.*
			Paraffins	*Naphthenes*	*Benzenes*	
Light paraffinic	1.5–10	0– 6	46–61	22–32	12–25	0.897–0.929
Paraffin naphthene	1–6	0– 6	42–45	38–39	16–20	0.897–0.908
Naphthenic	Trace	0– 6	15–26	61–76	8–13	0.895–0.912
Benzenoid	0–0.5	0–20	0– 8	57–78	20–35	0.950–0.970

The light, low boiling fractions contain the largest proportion of paraffins. No petroleum has ever been found which contains unsaturated hydrocarbons of the olefin type, at least in the lighter distillates which can be separated by distillation without decomposition. The hydrocarbons of the C_nH_{2n} series are naphthenes and those of the higher carbon ratios, C_nH_{2n-2} to C_nH_{2n-8} et cetera, occurring in the lubricating-oil distillates, are evidently polycyclic hydrocarbons. According to Mabery (22), the distillable lubricating fractions of Cabin Creek petroleum are mainly of the series C_nH_{2n-4}; the distillable lubricating oil fractions of Baku oil are mainly of the series C_nH_{2n-10}; and the corresponding fractions of Sour Lake, Texas, oil are of a series C_nH_{2n-12}. Mabery also showed that many of the hydrocarbon fractions separated from undistilled residuum by the action of solvents were sensitive to heat and could not be distilled under a good laboratory vacuum without decomposition.

NITROGEN BASES

J. R. Bailey (1) and his co-workers have shown that certain California petroleums, having a relatively high nitrogen content, yield no bases on acid extraction, but that the distillates contain bases which are readily extracted by dilute acid. Their observations show that the crude petroleum contains complex nitrogen derivatives which are sensitive to heat and are rapidly decomposed at temperatures above 200°C., in the kerosene boiling range, to give nitrogen bases as decomposition products. A recent private communication from Treibs reports that the California petroleums which yield dis-

tillates containing nitrogen bases are also relatively rich in chlorophyll porphyrins and that a study of these oils is in progress.

The discovery of chlorophyll porphyrins in asphalt and asphaltic petroleums by Treibs (41) is probably the most significant discovery ever made with respect to the origin of petroleum. Its significance is in showing a complete history of temperatures so low as definitely to preclude the formation of petroleum by heat decomposition of fatty oils or any other known possible raw material.

From the presence of aetio-porphyrins which are formed by loss of CO_2 from the corresponding acid derivatives, Treibs concluded that the organic material may have been heated to a temperature as high as 200° C., but he evidently overlooked the fact that decarboxylation of chlorophyll porphyrins takes place in a few hours in the digestive tract of animals.

ASPHALTS

All asphalts and all asphaltic petroleums examined contain chlorophyll porphyrins. Treibs considers that the clear asphalt-free oils had lost their porphyrin content by adsorption during filtration through adsorbent material. These results also show that chlorophyll-bearing plants (algae) existed as early as Devonian and probably as early as Silurian time. Due to the rapidity with which these chlorophyll derivatives are decomposed by oxidation, Treibs considers that their presence in oil shales, asphalts, and asphaltic oils indicates that in the original deposition of the organic material anaerobic conditions must have been brought about quickly, as by covering with sediment. The same consideration definitely excludes the assumption that asphalts have been formed by the oxidation, by air or evaporation, of petroleum. As Treibs states,

> In oils of medium viscosity, with considerable asphalt content, one has a more original oil, while the thinner, lighter colored oils represent natural raffinates.

He further suggests that one can expect that certain classes of substances will be found very little changed in petroleums and bitumens.

In the case of a Triassic oil shale from near Meride in Croatia, Treibs found 0.4 per cent of porphyrins, corresponding with more than half as much as the chlorophyll content of dried green leaves. In contrast with the relatively high porphyrin content of oil shales and asphalts and asphaltic petroleums, lignites and cannel coals showed only traces of porphyrins. This indicates that the source material of coal was very different from that of petroleum or that the prevailing biochemical conditions were very different.

The discovery of chlorophyll porphyrins in oil shales, asphalts, and petroleums suggests that green algae may have contributed largely as source material for petroleums (15). Few chemical studies of algae have been made. Some of them contain considerable fatty oil, but Stadnikoff (32) has pointed out two instances where abundant growths of algae result in semi-solid materials consisting largely of products derived from fatty oil content. In a shallow brackish lake in southern Russia an abundant growth of the green alga, *Bobriococus braunii*, forms masses of rapidly fermenting materials, evolving hydrogen sulphide, and when air-dried yields a material "balchaschite" which is semi-solid and which consists largely of polymerization products of unsaturated fatty acids. Stadnikoff and others, however, consider this material as probably related to cannel coal or bog-head coals. In a lagoon in southern Australia, Thiessen (37) observed the formation of masses of semi-solid fatty material from the alga *Elaeophyton coorongiana*. A sample of the material, called coorongite, gave 57 per cent of oil consisting in part of non-saponifiable oil. These results, together with the findings of Treibs, suggests that oil-bearing algae may have been an important source material of petroleum. Certainly we can no longer confine our speculations to fatty oils of fish, foraminifers, or diatoms.

The fatty material from algae, such as coorongite, forming first a waxy or semi-solid substance, fulfills the condition advanced by many geologists that the original source material of petroleum must be solid or semi-solid in order to be deposited and preserved in the forming sediments. Trask and Hammar (40), in a thorough study of contemporary sediments, found practically no organic matter in the form of extractable oil.

NAPHTHENIC ACIDS

Petroleum naphthenic acids are usually separated from the distillates or from the alkali soaps formed in the still residues when the oil is distilled in the presence of caustic alkali. Pyhala (28) found in the case of two Russian petroleums that the distillates contained 11–12 times as much naphthenic acid as the undistilled crude oils, indicating that, like the nitrogen bases, the naphthenic acids are mainly decomposition products of more complex materials which are readily decomposed on heating. Von Braun (45) has shown that petroleum naphthenic acids are of three general types, aliphatic $C_nH_{2n}O_2$, monocyclic $C_nH_{2n-2}O_2$, or bicyclic $C_nH_{2n-4}O_2$. Some of them are optically active. Petroleum from northern Germany, Rumania, California, and Texas all contain the same monocyclic and bicyclic types of

acids. The monocyclic acids are derivatives of cyclopentane, $C_5H_9 \cdot (CH_2)_xCO_2H$. The only similar acids found in nature are the chaulmoogric and hydnocarpic acids of chaulmoogra oil, which acids contain the cyclopentene group. Acids of this type are so rare in nature that the structure of the petroleum naphthenic acids appears to be evidence of their formation by decomposition of polymers of unsaturated fatty acids originally present in the petroleum source material.

SULPHUR DERIVATIVES

Practically all of the sulphur derivatives so far investigated have been found in the distillates, and particularly cracked distillates produced by cracking processes. Thiophenes have been found in the latter, and in shale oils, but it is doubtful if they occur in undecomposed petroleum. Kewley (20) has stated that certain crudes yield sweet distillates, free from mercaptans, if distilled under vacuum below 140°C. but at this temperature decomposition of complex labile sulphur compounds takes place with the formation of mercaptans. It has been pointed out by Gruse (14) that the sulphur and nitrogen compounds in crude petroleums, prior to distillation, are for the most part unknown.

OPTICAL ACTIVITY

The fact that the higher-boiling fractions of petroleum show optical activity has long been regarded as disposing of the theory of the origin of petroleum from carbides. It is equally of importance as evidence against the more recent suggestion of Lind (21) that petroleum may have been formed from methane by the action of alpha radiation. In the light of other evidence as to low-temperature history, it should be recalled that Walden (46) regarded this fact alone as proving a relatively low-temperature history. The optical activity of oils derived from cholesterol has been noted by Zelinsky and Steinkopf (33).

The foregoing facts show clearly that we now know petroleum to contain many complex substances which are unstable even to moderate temperatures. Many of them are decomposed by heat much more readily than are the fatty acids or the hydrocarbons.

COMPLEXITY OF HYDROCARBON MIXTURE

Probably one of the reasons for the persistence of the heat-decomposition theory is the large number of hydrocarbons present in most petroleums. Petroleums contain the normally gaseous hydrocarbons, methane and ethane, dissolved under pressure, and also contain the normal paraffins and some of the branched chain paraffins, from propane up to those of more than 25 carbon atoms. They also

contain a large number of cyclic and polycyclic and benzenoid hydrocarbons. The range of composition with respect to types of the major constituents is shown in Table II.

Wilson (51) has pointed out that in both the paraffin and olefin series the change from one or a few hydrocarbons to a great many of the same series involves no great amount of net energy change or reaction heat. However, one of the puzzling facts is the universal presence of small proportions of benzenoid hydrocarbons. Francis (11) has also treated this subject from the thermodynamic standpoint and states that the formation of aromatic hydrocarbons from paraffins requires temperatures within the range of 550°–900°C. This evidently assumes the splitting off of hydrogen. According to Francis, the reactions possible below 550°C. are quite *different in kind*. It is therefore wrong to assume that the formation of benzenes which is characteristic of the results obtained experimentally above 550°C. may also proceed at the much lower temperature associated with petroleum deposits at much slower rates during geologic time.

The extremes of petroleum composition, as shown in Table II, should also be noted. If what may be termed the hydrocarbon dispersion and isomerization has been due to heat, even at relatively low temperatures through long periods of time, then petroleums would be much more alike in composition; would, in fact, be *equilibrium mixtures*. However, the variation in the chemical character of petroleums is much greater than can be reasonably explained by different intensity or duration of thermal action.

Barton (2) has observed certain general consistencies between the A. P. I. gravity and composition as related to depth and age of petroleum in the Gulf Coast area which, if borne out in other fields, or if the exceptions could be satisfactorily explained, would at least show that petroleums are progressively altered with depth (temperature and pressure) and age. In this connection it is of interest to note, as pointed out by Barton, that the naphthenes and benzene hydrocarbons occur in largest per cent in the youngest and shallowest Gulf Coast oils. The older and deeper oils in this area are lighter and more paraffinic. Washburne (48) has argued, from general theoretical principles, that if altered by heat and pressure, the older oils should be the heavier and contain the largest proportions of naphthenes and benzenes. Pratt (27) states:

> Whatever may be the exact sequence and nature of events in petroleum genesis, a theory of uniform and progressive cracking does not explain the observed facts.

These considerations led Pratt to suggest that petroleums were pro-

gressively hydrogenated, the hydrogen being derived from methane. The experimental conditions for decomposing methane and hydrogenating heavy oils are more extreme than for cracking alone. It should be noted, however, that the Healdton, Oklahoma, and Texas oil and many of the Wyoming and California oils do not follow the general relations shown by the oils of the Gulf Coast area.

The temperatures observed in the producing strata are significant. Some of our most prolific fields yield their oil from geologically recent sands whose bottom-hole temperatures do not exceed 100°F. and whose strata are only slightly arched or otherwise disturbed. It has often been assumed that even slow uplifts and bending of the strata could produce temperatures sufficient for the decomposition of organic material. Mere compaction is no doubt often mistaken for heat metamorphosis. Heald (17) states:

> Not enough measurements are available to permit any conclusion as to the possible influence of a great, gentle uplift like the Bend arch on earth temperatures,

and that in wells thus far measured the depth of the granite basement has had no relation to the temperature. At Oklahoma City a temperature of 100°F. is encountered at 4,100 feet. In southwest Texas a rise of 1°F. for each 50–60 feet is noted, while in the Permian basin of West Texas and the Panhandle area the temperature rise is 1°F. for about 100 feet of increasing depth. It may reasonably be assumed that the present bottom-hole temperatures are much higher than the temperatures of the original sediments when laid down, and that the present temperatures may be at or near the maximum for the entire period. The temperatures observed at the bottom of wells about 8,000 feet in depth vary from about 150°F. to 170°F. (43). McCoy and Keyte (23) state: "Most of the known oil fields surely were formed at temperatures lower than 140°F.," which is far below the temperature required to decompose or isomerize oils such as paraffins, naphthenes and benzenoid hydrocarbons at any measurable rate. Seyer (30) has employed the velocity constants for cracking, determined by others, and calculated that at 212°F. the higher paraffins have a stability greater than the element potassium, and the "one-half life period" is about 3.68×10^{14} years and that "any buried waxy material must have been at a temperature of at least 302°F. to allow for its transportation into petroleum within the limits of geologic time." In fact, the one-half life period for the decomposition of wax at 302°F. (150°C.) is 1.15×10^{10} years. Study of the lead-uranium ratio of the mineral cyrtolite, found in a pegmatite intrusion at Bedford, New York, which geologists place as dating from the early Ordovician, show the age of the early

Ordovician to be about 3.8×10^8 years. Then, according to the reaction velocities calculated from measured cracking rates, about twenty times the *whole* of geologic time since the Ordovician and a temperature of 300°F. for the whole of this time would be necessary to decompose half of a quantity of buried wax to oil or other products.

Using the temperature gradient observed in the Permian basin of West Texas, we find that no petroleum should be formed by heat decomposition in geologic time short of a depth of about 28,000 feet.

In making his calculations, Seyer was seeking evidence for the formation of petroleum by heat decomposition. He was led, like Washburne, to reason that dense saturated molecules with a low hydrogen-carbon ratio, such as the polycyclic naphthenes, should be produced to a greater and greater extent with increasing time, temperature, and pressure. Exactly the opposite is strikingly shown by many light, highly paraffinic but geologically old oils and the wax-free, heavy naphthenic oils of many of the Gulf Coast and California pools of much more recent origin, as already noted.

No entirely consistent relation has been discovered between the composition of petroleums and their age or depth of occurrence. The question is evidently complicated by alterations in composition due to selective adsorption of asphaltic and other material of high molecular weights during migration of oil through the rocks, to chemical reaction with sulphur and perhaps other causes. It appears to be more probable, and also more consonant with the evidence of low-temperature history, that the wide variations in chemical character of different petroleums have their origin chiefly in the character of the original material deposited in the submarine sediments, or possibly in differences in the biochemical influences in the early stages of their history (6).

Pressure may conceivably have had a marked effect in the formation of petroleum, although the hydrostatic pressures even in our deeper wells seldom exceeded 150 atmospheres. Pressure in general favors polymerization of olefinic materials, but the ease with which many unsaturated substances polymerize spontaneously indicates that the effect of the rather moderate pressures, particularly at shallow depths, may have been important. The formation of coorongite and balchaschite from the fatty oils in the algae, already noted, indicate that polymerization of unsaturated fatty oils to solid or semi-solid material is one of the first changes to take place, as suggested by Stadnikoff (32). The highly insoluble character of the kerogen of oil shales and most of the organic material in cannel coals indicates that it is highly polymerized. Evidence that such material contains cyclic

or naphthenic groups is furnished by Stadnikoff, who found bicyclic hydrocarbons of the series C_nH_{2n-2} as major constituents of the oil produced on hydrogenating a Siberian bog-head coal by the method of Bergius. A lower degree of polymerization, or less unsaturated character of the original material, may account for the lubricating oil fractions of petroleum. Engler suggested that polymerization of olefins possibly accounted for the presence of naphthenic hydrocarbons in petroleums. The polymerization of the more reactive olefins by fullers earth is well known, and it has been recently shown that this property is by no means confined to fullers earth, but is a property of a wide variety of sedimentary rocks, particularly the clays and shales and to a lesser degree the sandstones (5).

In view of the evidence given in the preceding pages, the conclusion may be warranted that organic materials as stable as the paraffins, waxes such as the montan waxes and the kerogen of oil shale, once formed and sealed in the sedimentary rocks *normally undergo no further changes due to the influence of heat.* If this view is correct, the problem of how a few paraffins may be chemically "dispersed" and rearranged to a great number of hydrocarbons, does not exist. Rather, the hydrocarbons found in petroleum must mainly have been formed as such in the gradual biochemical anaerobic degradation of the organic materials buried in the sediments.

POSSIBLE SOURCE MATERIALS FOR BIOCHEMICAL PRODUCTION OF PETROLEUM

Students of petroleum geology have differed widely as to the source material and source beds of petroleum. Probably very few believe that petroleums have been derived entirely from one type of material. However, the present discussion has to do with the chemical types of raw materials; and indirectly with physical or geological conditions which are indicated by the chemical evidence. The work of Treibs, showing the derivation or association of petroleum source material with chlorophyll-bearing algae or plant life, implies a shallow-water plankton. There is much geological evidence for such conditions of deposition which can not be reviewed here.

The principal types of organic substances which have to be considered as the main source material for petroleum are as follows.

1. *Cellulose.*—Cellulose readily yields methane under anaerobic conditions. The fact that methane is formed in peat and remains in certain coals, entirely unaccompanied by oil, is evidence that cellulose alone does not produce the higher paraffins, or oil, by anaerobic fermentation, such as we are familiar with. The fact that the reduction

of carbon monoxide, by hydrogen in the presence of cobalt catalyst, as in the Fischer process, and that cellulose can be converted by hydrogenation under relatively high temperatures and pressures with caustic soda as carried out by Berl (4), to a series of paraffins, may be significant, although no result of this nature has been observed as a result of biochemical reduction. The conditions of Berl's and Fischer's processes are far removed from natural conditions.

2. *Starches and sugars.*—Water-soluble sugars would, of course, quickly be lost. However, Taylor (35) has shown that sugars and starches undergo anaerobic fermentation in the slightly alkaline conditions under a layer of sodium-clay, and yield products which are entirely gaseous, the gas consisting principally of methane.

3. *Proteins.*—These are rapidly and almost completely destroyed by putrefaction. Small proportions of protein degradation products may be preserved under anaerobic conditions and may account for the nitrogenous material in petroleum which yields nitrogen bases. Sulphur, as free sulphur, hydrogen sulphide and complex sulphur derivatives, are so abundant in many crude petroleums that the reduction of sulphates would appear to be the most plausible source of the sulphur. Clays such as fullers earth have been shown experimentally to catalyze the formation of mercaptans by the addition of hydrogen sulphide to olefins. Hydrogen sulphide has been observed in abundance in the fermentation of the masses of algae incident to the formation of balchaschite. Simple amines of the type of ptomaines have not been found in petroleums.

4. *Lignins.*—Lignins are very resistant to micro-organisms, and are converted to humic acids. However, they may be broken down under conditions not yet observed or studied. Taylor (35) states that by anaerobic fermentation under the alkaline conditions resulting from base exchange under sodium clay, lignin was attacked. Lignin is the only natural organic material occurring in abundance which may have furnished the benzene derivatives found in petroleums without assuming high-temperature conditions.

5. *Oleo-resins.*—These generally lose their volatile oils, as in amber, the fossil copals, resinous inclusions in coal, but the resins are preserved through long periods of geologic time.

6. *Waxes.*—The natural waxes, consisting mainly of esters of the higher, solid alcohols and complex organic acids, are also exceedingly resistant under natural conditions. They do not appear to be attacked by micro-organisms. The waxes in peat show no appreciable change in composition with increasing age.

7. *Fatty oils.*—It has long been known that fatty oils are hydro-

lyzed in a few years, losing their glycerine. Wells and Erickson (49) found that a solid material, obtained from the wreck of a small ship which had carried a cargo of herring, consisted chiefly of the calcium and magnesium salts of the fatty acids of herring oil and suggested that in the presence of sea water the formation of such insoluble fatty salts may be one of the early processes involved in the formation of petroleum.

That the putrefactive decomposition of the organic matter deposited in the sediments is an initial step in the formation of petroleum has long been generally recognized. Engler (10) suggested that fatty acids probably lose CO_2 at an early stage. The prevailing opinion, however, seems to be that bacterial action soon ceases altogether. Probably few subjects have been the object of so much speculation and so few attempts to obtain experimental evidence as the question of the rôle of bacteria in the formation of petroleum. There is no published evidence of the actual formation of liquid hydrocarbons by bacteria. McCoy and Keyte (23) note that following initial putrefaction the decomposition by anaerobic forms must proceed at a very slow rate, a condition necessary for the retention and later accumulation of the material. That many species of bacteria found in soil waters are able to utilize petroleum or the more complex hydrocarbons under aerobic conditions appears to be well substantiated. Tausz and Donath (36) found that in general the ease with which a hydrocarbon is attacked increases with the length of the chain. However, very few anaerobic studies have been carried out. The work of Taylor on the slow anaerobic degradation of fatty oils and fatty acids under sodium-clay appears to be the only experimental study of such changes thus far published. Triacetin formed methane, and tributyril formed "gaseous paraffins." Stearic and palmitic acids were slowly attacked, but the products formed were not determined. At present the depth in the sediments at which bacterial action ceases is much in dispute. Unfortunately, the poorer the experimental technique, the deeper bacteria are likely to be reported.

PETROLEUM IN TRANSITION STAGES

Entirely aside from chemical considerations, geologists have stated that the organic source material from which petroleum has been formed must originally have been deposited in the sediments as solid or semi-solid material, the oil and gas now found being sealed from escape by overlying impervious clays or shales. This is consistent with the findings of Trask, whose samples were collected at or near the surface of the sediments.

Engler recognized the differences between his unsaturated distillates, made by the pyrolysis of fats, and petroleum, and suggested the term protopetroleum for the undiscovered transition stage of petroleum, assuming such a material to be derived from fats by heat decomposition. No material resembling Engler's distillates has been found in nature. The findings of Trask, the solid mixtures of coorongite and balchaschite formed from algae, the discoveries of Treibs and the observations of Taylor all harmonize with the primary physical requirement postulated by geologists. Accordingly it might be expected that protopetroleums in transition stages will be found in geologically recent strata, in the form of solid or semi-solid material. Such material might be expected to be a mixture of hydrocarbon oils together with polymerized fatty, or naphthenic acids. The writer suggested several years ago (Rochester, New York, 1931) that asphalt might repay investigation from this point of view. Certainly asphalts are not oxidation products of petroleum, but rather their oxygen content has survived from the original source material. The findings of Treibs are certainly strong evidence for this point of view. Asphalts would appear to be either petroleum in transition or "near-petroleums" formed coincident with petroleum. It has often been suggested that the source material of petroleum has been laid down in estuarine sediments. The anaerobic conditions which Treibs' findings require and which Taylor's work suggests, demand rapid or frequently intermittent sedimentation. The study of the organic material, probably still well disseminated, in Tertiary and Recent deposits which fulfill these conditions may fill in some of the gaps in the chemical history of petroleum.

SUMMARY

1. The geological antiquity of organic minerals other than petroleum, particularly the kerogen of oil shale, indicates a low-temperature history.

2. The temperatures of our deeper wells, about 170°F., is not sufficient to decompose or "crack" half of the given quantity of paraffin hydrocarbons within twenty times all of geologic time, according to the calculations of Seyer, without assuming some now unknown catalytic agencies.

3. Petroleums contain several types of constituents which are more easily decomposed by heat than the hydrocarbons or fatty acids. These labile constituents are complex substances which yield nitrogen bases, naphthenic acids, and sulphur derivatives. The presence of optically active constituents is also evidence of low-temperature history.

4. The presence of chlorophyll porphyrins is evidence of (a) low-temperature origin and history, (b) derivation of petroleums or association of the original organic source material with chlorophyll-bearing plant life, probably marine algae, (c) anaerobic conditions continuously or intermittently during the deposition of the original source material.

5. The chemical evidence agrees with the maximum temperature of petroleum formation, 140°F., suggested by McCoy and Keyte. The chemical evidence is consistent with the general conditions of deposition and oil formation postulated by geologists.

6. Petroleums are not equilibrium mixtures.

7. The wide differences in the compositions of petroleums probably are the result of the differences in original source materials or in biochemical history.

8. Asphalt is a primary product, not a derivative or oxidation product, of petroleum.

9. Fatty oils are still to be regarded as the principal source material of petroleums.

10. The indicated low-temperature history of petroleum favors the view that the hardening or so-called lithification of sedimentary rocks is due entirely to compaction and the deposition of cementing material from solution.

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SOME TENTATIVE CORRELATIONS ON THE BASIS OF GRAPTOLITES OF OKLAHOMA AND ARKANSAS[1]

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ABSTRACT

The object of this paper is to present a series of tentative correlations from the evidence of graptolite zones extending from near the middle of the Arbuckle limestone, up through the upper Arbuckle, Simpson, Viola, Sylvan, and Henryhouse of the Arbuckle Mountain region, and the Stringtown-Womble, Big Fork, Polk Creek, and Blaylock of the Ouachita region. While only evidence from graptolites is presented here, other zone fossils have been used extensively in determining some of the correlation which is illustrated in two papers by the writer.[3]

INTRODUCTION

The presence of graptolites in Oklahoma has been known for more than 30 years, but no very serious study of them was made until about 4 years ago, when the writer became interested in them. Taff[4] in 1903 listed with questionable determinations two graptolites from the Viola limestone and two from the Sylvan shale. In 1911, Ulrich[5] placed *Didymograptus artus* provisionally in the upper part of the Arbuckle limestone. Honess[6] recognized poorly preserved graptolites in the Polk Creek shale of southeastern Oklahoma in 1923. Morgan[7] listed the same four graptolites from the Viola and Sylvan that had been listed earlier by Taff.

In Arkansas in 1892, Gurley[8] listed and described many graptolites. Also, he[9] illustrated a few and listed a large number of grap-

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[3] C. E. Decker, "The Stratigraphy and Physical Characteristics of the Simpson," *Bull. Oklahoma Geol. Survey 55* (1931), pp. 54–86.
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[4] J. A. Taff, "Tishomingo, Oklahoma (Indian Territory)," *U. S. Geol. Survey Atlas Folio 98* (1903), pp. 3, 4.

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tolites in the *Journal of Geology*. Miser[10] noted the presence of graptolites in the Ordovician and Silurian formations of Arkansas, and in 1929 Miser[11] and Purdue listed large numbers of graptolites from Arkansas, which were identified by E. O. Ulrich. Croneis[12] noted the presence of graptolites in the formations of Arkansas. Graptolites of the Viola limestone were listed by zones by the writer[13] in 1933. With Ruedemann[14] the writer described and illustrated thirty species and varieties of graptolites from the Viola limestone. The graptolites of the Simpson group were described by the writer[15] in 1935. In the same year he[16] described the graptolites from the Henryhouse shale of Oklahoma. In this same year also he[17] described graptolites from the Sylvan and Polk Creek shales. In addition, titles of four papers on graptolites are on the program of the twenty-first annual meeting of the Association at Tulsa in March, 1936. Then beyond these, there is considerable material for which drawings and identifications have been made.

ACKNOWLEDGMENTS

Above all the writer is greatly indebted to Rudolf Ruedemann for his expert and painstaking supervision, especially until the writer developed some facility in drawing and identifying the graptolites. Even after that, he checked identifications and shaded practically all of the drawings. Acknowledgment is made for assistance in the field to Hugh D. Miser, John Fitts, Rex McGehee, Norval Ballard, Ross Maxwell, J. O. Beach, Henry Phillips, numerous students from the University of Oklahoma, and many others who have assisted for short periods. Acknowledgment is made for funds to defray part of the expense of the study to the National Research Council, University of Oklahoma Research Fund, Oklahoma Academy of Science Research

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Fund, and recently, the Oklahoma Geological Survey. As doubtless is the case in many research projects, it has been necessary for the writer to meet a considerable part of the expense of the study personally.

GRAPTOLITES FROM MIDDLE ARBUCKLE LIMESTONE

A very significant graptolite horizon has been found near the middle of the Arbuckle limestone about 4,600 feet below the top on the east side of U. S. Highway 77, on Chapman's ranch in Sec. 18, T. 2 S., R. 2 E. Some excessively weathered fragments of graptolites were secured from this locality in 1928 by Rex McGehee and the writer. Later, C. L. Dake collected and sent some of the weathered fragments to the Sinclair Oil Company at Tulsa and to the United States Geological Survey in Washington, D. C. Frederic A. Bush and E. O. Ulrich kindly supplied some of this material for study, but it was very fragmental and much weathered.

The graptolites occur in a heavy limestone bed about 12–15 inches thick. Part of it is crystalline, somewhat conglomeratic in places, and contains irregular shaly films scattered through it. As the graptolites are sparse, large blocks of the limestone were excavated with shovels and heavy bars and split with a heavy sledge. From these deeper, unweathered rocks some good parts of colonies were secured, which are all of the dendroid, or branching types.

Table I shows the graptolites from this new low zone in the Arbuckle limestone. The table is modified from Ruedemann[18] by the addition of four forms, one species of which (*Callograptus crassus*) is new. The other three are added from his text, in part due to changes Ruedemann has made since its publication, and the alphabetical arrangement also is changed.

Great care was taken in drawing and checking the identification of these graptolites from this new low horizon in the Arbuckle limestone. If our identifications are correct, these graptolites have supplied some of the most significant evidence secured from the Arbuckle limestone in connecting this part of it with the upper Cambrian in the regions shown in Table I. Practically all the fossils (except the graptolites) collected by the writer and assistants from the Arbuckle limestone and the Honey Creek formation, have been forwarded to E. O. Ulrich of the United States Geological Survey. Josiah Bridge states that evidence from these other invertebrates seems to place the Ordovician-Cambrian contact several hundred feet below this graptolite zone. Even this would move the contact up about 3,000 feet, or

[18] Rudolf Ruedemann, "The Cambrian of the Upper Mississippi Valley," Pt. 3, "Graptoloidea," *Bull. Public Mus. Milwaukee*, Vol. 12 (1933), p. 313.

more, above the horizon on which there has been a tendency to place it of late. Solution of the problem in regard to the apparent conflict in evidence from the differing faunas will of necessity await later information. Possibly some suggestions may come from the graptolite zone, which is more than 3,000 feet higher in the Arbuckle, and which, at that horizon, is very low in the Ordovician. With reference to the Trempealeau formation with which these graptolites seem to relate

TABLE I

MIDDLE ARBUCKLE GRAPTOLITE ZONE

	Oklahoma	*Wyoming*	*Wisconsin*	*Minnesota*	*Tennessee*	*South Dakota*	*Vermont*	*Quebec*
Haplograptus vermiformis Rued.			×		×			
H. wisconsinensis Rued.			×	×				
Dendrograptus edwardsi Rued.			×	×				
D. edwardsi var. *major* Rued.			×	×	×			
D. hallianus (Prout)	×		×	×				
D. hallianus spissus Rued.	×		×					
D. kindlei Rued.	×							×
D. sparsus Rued.			×	×				
D. thomasi Rued.	×					×		
Callograptus antiquus Rued.					×			
C. crassus n. sp.	×							
C. staufferi Rued.	×		×	×				
Acanthograptus priscus Rued.				×				
Dictyonema sp.			×					
D. minnesotense Rued.				×				
D. schucherti Rued.	×						×	
D. wyomingense Rued.		×						
Masligograptus sp.	×		×					

this Arbuckle graptolite horizon, it may be said that an excellent article on the Cambrian of the Upper Mississippi Valley area has been written recently. In it the authors[19] have listed a *Dendrograptus* from the Ironton member of the Franconia formation below the *Eoorthis* zone and far below the base of the Trempealeau formation.

DIDYMOGRAPTUS PROTOBIFIDUS ZONE

About 3,700 feet above the lower graptolite zone already noted and between 800 and 900 feet below the top of the Arbuckle limestone, there occurs a *Didymograptus protobifidus* zone about 30 feet in width. Though they are scattered and fairly common throughout the zone, they are most abundant in thin films of shale which alternate with thin

[19] J. M. Wanenmacher, W. H. Twenhofel, and G. O. Raasch, "The Paleozoic Strata of the Baraboo Area, Wisconsin," *Amer. Jour. Sci.*, Vol. 28 (1934), p. 14, and table opp. p. 7.

limestones near the top of the zone. This species was recognized and described by Gertrude L. Elles.[20] In working out this species and its transients, she made a very significant contribution in the study of dependent graptolites in England. By recognizing this earlier form, and by differentiating it from the true *D. bifidus*, she gave greater significance to the latter by restricting its time range. *Phyllograptus anna* was found in the lower part of the *D. protobifidus* zone here, as it occurs also about the middle of the Skiddaw slates of Great Britain. *P. anna* has been recently identified by the writer from Smithville, Arkansas, in material supplied for study by Frederic A. Bush. *P. anna* is common in the middle of the Deepkill of New York and it occurs also in Nevada and Quebec.

This *D. protobifidus* zone in Oklahoma is the first to be recognized in this country. It is possible that when the dependent graptolites in the various regions are studied with the characteristics of this species and its transients in mind, this zone may be differentiated elsewhere. In Oklahoma this zone is nearly 1,000 feet below the true *Didymograptus bifidus-D. artus* zone, which is well above the base of the Joins formation of the Simpson group.

DIDYMOGRAPTUS BIFIDUS-DIDYMOGRAPTUS ARTUS ZONE

Didymograptus artus was traced in various outcrops of the Joins formation, and later this zone was found at a depth of about 6,000 feet in the Oklahoma City oil field. But *D. bifidus* was not known from this state until this week, January 15, 1936, when search for it, by Robert H. Dott and the writer at the north end of the Criner Hills, was rewarded by finding several typical specimens of this species in the zone with *D. artus*, as they commonly occur in Great Britain. It is thought now that this zone is Beekmantown in age, and that the brachiopod occurring below it, identified as *Orthis costalis*, either is not that species, or that it has an exceptionally long range here.

The writer has a good specimen of *D. bifidus* furnished him by E. O. Ulrich from a shaly phase in the Black Rock limestone, Black Rock, Arkansas. It occurs in the Deepkill of New York, in the middle and upper Arenig of Great Britain, and it occurs in Quebec, Norway, Belgium, and France. Until recently only two graptolites were known from the Simpson group, but this adds a third species.

BROMIDE UPPER SIMPSON GRAPTOLITE ZONE

Until recently only a single graptolite, *Diplograptus maxwelli*, was known from the upper part of the Bromide formation. This species

[20] G. L. Elles, "Skiddaw Graptolitic Fauna," *Summary Progr. Geol. Survey Great Britain and Mus. Practical Geol. for 1932*, Pt. 2 (1933), pp. 98, 99.

was described by the writer and its importance in local correlation of the Bromide formation noted in the *Proceedings* of the National Research Council.[15] About 2 months ago T. A. Hendricks, of the United States Geological Survey, found a fragment which with others found later has been identified as *Dicellograptus mensurans* Ruedemann because of its thinness and very narrow thecae. This species occurs in the Normanskill shale where Ruedemann thinks it represents the most primitive member of the genus. The presence of this species in the upper part of the Bromide gives the first suggestion that this upper part of the Simpson may be equivalent to the basal part of the Normanskill of New York, and thus of the lower part also of the Stringtown shale of Oklahoma and the Womble shale of Arkansas. Fragments of several other species of graptolites have been found recently in the upper part of the Bromide, where they occur in exceedingly sparse distribution, but none of them has been identified as yet.

STRINGTOWN AND WOMBLE SHALE AND BASAL VIOLA ZONE

And one might add Normanskill[21] and Glenkiln[22] zone, for the zone in this southwestern region contains a typical Normanskill and Glenkiln graptolite fauna. In Table II a rich graptolite fauna is given for five regions, two in Oklahoma, and the others in Arkansas, New York, and Great Britain. This does not give the complete distribution of all the forms, as some occur widely scattered in various states, in Canada, China, and New Zealand.

This indicates clearly that the upper and middle parts of the Stringtown shale are equivalent to the basal part of the Viola limestone. Some of the basal graptolites of the Stringtown, especially *Nemagraptus gracilis*, have not been found in the Viola limestone. Some of the fissile shales interbedded with the basal Viola limestones have some of the characteristics of the Stringtown shales though they are more brownish or less black. In several places there is evidence of an unconformity between the Bromide of the Simpson and the Viola. Accordingly, it was thought probable that the basal part of the Stringtown is represented in the Arbuckle Mountains only by the unconformity. However, if the tentative identification of a new graptolite from the upper part of the Bromide formation of the Criner Hills, as *Dicellograptus mensurans*, proves to be correct, there is a suggestion that this Normanskill form may indicate that the upper part of the Bromide is equivalent to the very basal part of the Stringtown, with

[21] Rudolf Ruedemann, "Graptolites of New York (Higher Beds)," *New York State Mus. Mem. 11*, Pt. 2 (1908), Tables 1 and 2, pp. 13–16.

[22] G. L. Elles and E. M. R. Wood, *Monograph of British Graptolites* (1901–1918), pp. 1–536, Pls. 1–52.

TABLE II

	Stringtown Shale, Oklahoma	Lower Viola Limestone, Oklahoma	Womble Shale, Arkansas	Normanskill Shale, New York	Glenkiln Shale, Great Britain
Climacograptus antiquus	×				×
C. bicornis	×	×	×	×	×
C. bicornis var. *peltifer*	×		×	×	×
C. bicornis var. *tridentatus*	×				×
C. eximius	×	×			
C. cf. *oligotheca*			×		
C. parvus	×	×	×	×	
C. cf. *typicalis*		×	×		
Corynoides gracilis var. *perungulatus*	×			×	
Cryptograptus insectiformis	×	×		×	
C. tricornis	×	×	×	×	×
Desmograptus sp.			×		
Dicellograptus divaricatus	×		×	×	×
D. divaricatus var. *salopiensis*	×			×	×
D. gurleyi		×	×	×	
D. intortus			×	×	×
D. sextans var. *exilis*	×			×	×
Dicranograptus cf. *nicholsoni*	×	×	×		×
D. nicholsoni var. *diapason*			×	×	
D. nicholsoni var. *geniculatus*	×	×			
D. nicholsoni var. *parvangulus*	×	×	×	×	
D. ramosus			×	×	×
D. Arkansasensis		×	×		
D. spinifer	×		×	×	×
D. zic-zac	×	×			×
Didymograptus sagitticaulus	×		×	×	
D. sagitticaulus var. *minimus* n. var.	×		×		
D. cf. *serratulus*	×			×	×
Diplograptus (*Glyptograptus*) *angustifolius*	×		×	×	
D. cf. *calcaratus* var. *basilicus*			×		
D. euglyphus	×	×	×	×	×
D. euglyphus var. *pygmaeus*	×			×	
D. incisus	×		×		
D. cf. *semotus*		×			
Glossograptus ciliatus		×	×	×	
G. quadrimucronatus var. *maximus* n. var.	×	×	×		
G. quadrimucronatus var. *spinigerus*	×	×			×
Glyptograptus cf. *teretiusculus*	×	×			×
Lasiograptus bimucronatus			×	×	×
L. mucronatus	×		×	×	×
Nemagraptus gracilis	×		×	×	×
Thamnograptus capillaris	×			×	×

a corollary that the unconformity mentioned above represents an interval of short duration.

VIOLA-BIG FORK ZONE

Besides the graptolites in the basal part of the Viola correlated in the preceding paragraphs with a part of the Stringtown and Womble

shales, twenty-four others have been listed by zones from the Viola.[23] Several graptolites, as well as *Cryptolithus tesselatus* Green, pass from the upper part of the Viola proper into the Fernvale phase at the top. As already noted, the basal part of the Viola has been correlated with Stringtown, Womble, Normanskill, and Glenkiln shales. The evidence seems to indicate that the rest of it is correlative with the Trenton, Utica, and Lorraine; and the Fernvale at the top with Richmond. Though extensive detailed collections have not been made from the Big Fork, enough have been collected from several zones, with *Cryptolithus tessellatus* traced into it, to show the practical equivalence of the Big Fork of the Ouachita Mountains and a part of the Viola limestone of the Arbuckle Mountains.

SYLVAN-POLK CREEK ZONE

Table III shows the practical equivalence of the Sylvan shale of the Arbuckle Mountains and the Polk Creek shale of the Ouachita Mountains, and graptolites collected by John Fitts east of Atoka supplied the first clear evidence of this relationship. Furthermore, shale with most of the physical characteristics of the Sylvan occurs

TABLE III

	Sylvan Shale, Oklahoma	*Polk Creek, Arkansas*	*Maquoketa Shale, Iowa, Wisconsin, Illinois, Missouri*	*Upper Hartfell, Great Britain*
Climacograptus mississippiensis	×	×		
C. putillus	×	×	×	
C. tridentatus var. *maximus*	×	×		
C. ulrichi	×	×	×	
Dicellograptus anceps		×		×
D. complanatus	×	×		×
Diplograptus calcaratus var. *trifidus*		×		
D. crassilestus	×	×		
Glossograptus quadrimucronatus var. *paucithecatus*		×		
Retiograptus sp.	×			

not only in Black Knob Ridge east of Atoka, but also in Johns Valley in one of the large erratic masses. The Sylvan and Polk Creek are linked also with the Maquoketa by means of the two graptolites. But still more significant is the fact the chief zone fossil of the upper Hartfell shale of Great Britain, *Dicellograptus complanatus*, occurs commonly in both the Polk Creek and Sylvan, thus tying them clearly

[23] Rudolf Ruedemann and C. E. Decker, *op. cit.*, Table I, p. 325.

with the upper Ordovician of England. This definitely places the Sylvan in the upper Ordovician with the Ordovician-Silurian contact at the top of it.

BLAYLOCK GRAPTOLITE ZONE

Miser and Purdue[24] have listed six species of graptolites identified by Ulrich from this zone. They were secured from the north bank of the Little Missouri River at the south edge of Blaylock Mountain in the Caddo Gap Quadrangle, Arkansas. A small collection secured from this locality by Miser, Fitts, and the writer contained one of these *Monograptus argutus* and an excellent specimen of *monograptus communis*. These with *Monograptus gregarius* would place the zone at the top of the middle division and base of the top division of the Birkhill shales of Great Britain in the lower part of the Silurian, but considerably above its base.

HENRYHOUSE GRAPTOLITE ZONE

This Silurian graptolite fauna from the Henryhouse shale of Oklahoma is a very significant one, in that no other such assemblage of monograptids has been found elsewhere in North America. Mono-

TABLE IV

	Oklahoma	*Maine*	*Great Britain*	*Europe*	*Australia*
Ascograptus sp.	×				
Mastigograptus beachi n. sp.	×				
Mastigograptus sp.	×				
Thallograptus phylloides n. sp.	×				
Monograptus bohemicus	×		×	×	×
M. crinitus var. *exilis*	×		×		
M. dubius	×		×	×	×
M. nilssoni	×	×	×	×	×
M. scanicus	×		×		
M. tumescens	×		×		
M. cf. *ultimus*	×		×	×	
M. vulgaris	×		×		
M. (*Linograptus*) *phillipsi* n. sp.	×			?	
M. (*Linograptus*) *phillipsi* var. *multiramosus* n. var.	×				
Cryptograptus sparsus n. sp.	×				

graptids are characteristic of the Silurian of Great Britain, Europe, and Australia, and some specimens of this graptolite fauna of Okla-

[24] H. D. Miser and A. H. Purdue, *op. cit.*, p. 45.

homa are found in all of these far distant regions. The cosmopolitan *Monograptus nilssoni* has been found in Maine and in all of the regions named.[25] R. R. Shrock[26] described as a new species *Monograptus falciformis* from the Mississinewa shales (Niagaran) of northern Indiana. His photograph of this form, together with his measurements of the specimen, indicate that it is very much like, and almost identical with, the proximal end of *Monograptus bohemicus*, of which a large number of well preserved specimens were available from Oklahoma. If, as is thought, these two forms are the same, the presence of *M. bohemicus* in these two regions would suggest a close stratigraphic connection between them. Another peculiarity of this Oklahoma Silurian graptolite fauna is that it contains only two sparsely branching types, and these are new forms, while other American Silurian graptolite faunas are dominantly dendroid and profusely branching. Ruedemann[27] has described 24 species and varieties in dendroid Silurian graptolite faunas of New York. Bassler[28] has described one of 52 species and varieties from Ontario, and there are 15 of the dendroid types in Shrock's Silurian fauna of Indiana. Eight of these Oklahoma Silurian monograptids occur in the lower Ludlow shales of Great Britain, with which the Henryhouse shale of Oklahoma may thus be correlated. This indicates that the Henryhouse shale is much higher in the Silurian than the Blaylock sandstone of the Ouachita Mountains of Oklahoma and Arkansas, the latter being equivalent to the upper part of middle or lower part of upper Birkhill of Great Britain, where nearly all of upper Birkhill, and all of Torannon and Wenlock, represent the gap between these two Oklahoma and Arkansas units.

Another peculiarity of this Oklahoma Silurian fauna is the presence in it of *Monograptus* (*Linograptus*) *phillipsi*. Nothing like this form has been found elsewhere, except in Bohemia, where one occurs that branches like it, but is shown with simpler thecae.

In conclusion, it may be said that another important graptolite fauna has been collected from the Arbuckle limestone, and the forms have been drawn and identified, but due to complex structural conditions, its exact position in the stratigraphic section has not been

[25] C. F. Decker, "Graptolites from the Silurian of Oklahoma," *Jour. Paleon.*, Vol. 9 (1935), pp. 434–46.

[26] R. R. Shrock, "A New Graptolite Fauna from the Niagaran of Northern Indiana," *Amer. Jour. Sci.* Ser. 5, Vol. 16 (1928), pp. 1–38. (a) p. 7, (b) pp. 35–38, Text Figs. 7, 8, 10e.

[27] R. R. Ruedemann, "Some Silurian (Ontarian) Faunas of New York," *New York State Mus. Bull. 265* (1925), (a) pp. 18, 19, Pl. 6, Figs. 1-8, (b) pp. 36, 37.

[28] R. S. Bassler, "Dendroid Graptolites of the Niagaran Dolomites at Hamilton, Ontario," *U. S. Nat. Mus. Bull. 65* (1909), pp. 1–63, Pls. 1–5.

determined. Accordingly, it is not used here. Also, there has not been opportunity to trace laterally the graptolite horizons discovered in recent years. The opportunity to trace these zones in the various outcrops throughout the mountains, will doubtless supply numerous additional species of graptolites, and supply more excellent evidence to assist in local and widespread correlation of the various stratigraphic units.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 3 (MARCH, 1936), PP. 312-314, 1 FIG.

GEOLOGICAL NOTES

CORRELATION OF BLUEJACKET SANDSTONE, OKLAHOMA

The Bluejacket sandstone member of the Cherokee shale north of the Arkansas River (the surface equivalent of the Bartlesville sand), is equivalent to the lowest sandstone unit of the Boggy shale in the Quinton-Scipio district, Oklahoma,[1] according to data obtained during the mapping of that district by a field party of the United States Geological Survey in the summer of 1934. A former correlation[2] made the Bluejacket sandstone equivalent to the uppermost sandstone member of the Savanna sandstone on the Kinta anticline south of Quinton.

The accompanying map (Fig. 1) shows the position of the base of the Bluejacket sandstone as traced by Wilson and Thom[3] southward to the south line of T. 9 N., R. 18 E., south of Enterprise, and the position of the base of the equivalent sandstone unit in the lower part of the Boggy shale, as determined by C. H. Dane and T. A. Hendricks east and south of Enterprise. The detailed mapping done in the Quinton-Scipio district extends only to the northeast corner of T. 8 N., R. 18 E. The McAlester district lies southwest of the area shown in Figure 1, its northeast corner being in the north-central part of T. 6 N., R. 17 E. Elsewhere the writers' tracing of the beds was done on the United States Geological Survey topographic map of the Sansbois Quadrangle.

In the mapping of the Quinton-Scipio district by Dane and of the McAlester district by Hendricks[4] the formations identified and mapped were those named by Taff.[5] It was found that these formations, which consist almost exclusively of sandstone and shale, exhibit striking lateral variations and that individual sandstone beds are

[1] C. H. Dane, H. E. Rothrock, and J. S. Williams, "Preliminary Map of the Quinton-Scipio District, Oklahoma," *U. S. Geol. Survey Prelim. Edition* (1935).

[2] C. W. Wilson, Jr., "Age and Correlation of Pennsylvanian Surface Formations and of Oil and Gas Sands of Muskogee County, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), pp. 511–17.

[3] W. T. Thom, Jr., unpublished mapping of the Quinton-Stigler-Poteau district, Oklahoma.

[4] T. A. Hendricks, "Geology and Coal Resources of the McAlester District, Oklahoma," *U. S. Geol. Survey Bull.* (in preparation).

[5] J. A. Taff, "Geology of the McAlester-Lehigh Coal Field, Indian Territory," *U. S. Geol. Survey Nineteenth Ann. Rept.* (1898), Pt. 3, pp. 435–39.

lenticular or grade into shale along the strike of the beds. This variation within the Savanna is so great that in the Quinton-Scipio district subdivisions of the Savanna sandstone were not mapped. An attempt was made, however, in that district to map subdivisions of the Boggy shale that are predominantly sandstone or predominantly shale. The

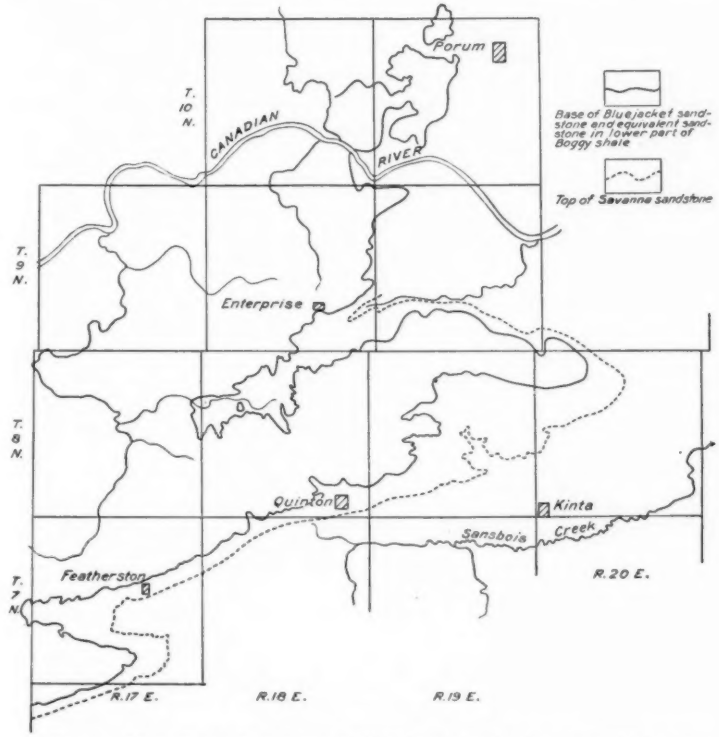

FIG. 1.—Map of area in east-central Oklahoma, showing in part position of outcrop of top of Savanna sandstone, position of base of Bluejacket sandstone as traced by C. W. Wilson, Jr., to south line of T. 9 N., R. 18 E., and position of base of equivalent sandstone unit in lower part of Boggy shale as traced by C. H. Dane and T. A. Hendricks.

lowest of these mappable sandstone units, which is the one equivalent to the Bluejacket sandstone, has a thickness ranging from 100 to 150 feet and its top lies 100–200 feet below the Secor (Blocker or upper Witteville) coal bed. The base of the unit lies 200–250 feet above the top of the Savanna sandstone in Ts. 7 and 8 N., R. 18 E., as computed

from measurements on the surface. However, H. A. Whitley's Allen No. 1 in the northwest corner SW. ¼, SW. ¼, Sec. 8, T. 8 N., R. 18 E., which began only a short distance below the base of the unit, penetrated 260 feet of beds, chiefly shale, before encountering limestone and sandstone which may represent the topmost bed of the Savanna.

Confirmatory evidence of the correctness of the correlation made in this discussion is afforded by the lithologic character of the exposures. The lowest part of the Boggy shale in the McAlester and Quinton-Scipio districts consists chiefly of dark shale, which is poorly exposed in a broad valley between the sandstone ridges of the Savanna and the ledges of sandstone higher in the Boggy shale. About 20 feet above the base of the Boggy in the McAlester district[6] lies the Lower Witteville coal. Exposures of this coal were not seen in the Quinton-Scipio district, but it is believed to be present, because coal fragments were reported from wells and in creeks at places where the coal at this horizon might be expected to occur. In the NE. ¼, Sec. 35, T. 9 N., R. 18 E., however, massively bedded sandstone at the top of the Savanna is exposed and also the overlying basal beds of the Boggy shale, which consist of velvety black pyritic shale containing several beds of coal, none of which exceeds 6 inches in thickness.

C. H. DANE
T. A. HENDRICKS

UNITED STATES GEOLOGICAL SURVEY
WASHINGTON, D. C.
January, 1936

[6] T. A. Hendricks, *op. cit.*

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DISCUSSION

CORPUS CHRISTI STRUCTURAL BASIN POSTULATED FROM SALINITY DATA[1]

In this paper the writer attempted an analysis of the general case of the history of connate fresh or salt waters in porous strata of young coastal plains and their mixing with waters entering the aquifers either at the outcrop or in positions downdip laid bare by erosion and covered by the sea. The chemical changes in the waters were considered only in the single case of the concentration or dilution of the chlorine content ("salinity") and the development of regional chlorine gradients in relation to structural gradients of the beds. Observed regional chlorine gradients in the Gulf Coast Pleistocene (and Pliocene?) aquifers of the Corpus Christi area were then studied.

Several points not discussed in the paper, and changes in stratigraphy since made, are here considered. John Doering has lately described the Willis formation of probable Pliocene age.[2] Strata formerly mapped as Lissie have been removed and placed in the Willis. Hence, the lower water-bearing beds studied in the Corpus Christi area may be Pliocene in age. A well developed caliche bed in the Willis indicates a period of semi-aridity which may have affected the surface waters which entered some of the earlier aquifers of the group. Younger caliches may be Recent. The Pleistocene was possibly a period without semi-arid climates in South Texas, although the salinity of the upper 300 feet of the Beaumont-Lissie series of aquifers suggests late Pleistocene aridity.

Doering's work on the pre-Beaumont agrees with Barton's and the writer's on the Beaumont in finding this whole series of post-Miocene beds to be of fluviatile origin except where tidewater and marine facies are found in a narrow zone beneath the present tidewater areas, interbedded in non-marine strata in the Beaumont and Lissie. Hence, most of the sampled areas of the aquifers originally contained waters of surface origin. Some must have been fresh waters, while some may have been saline because of concentration in the soil under a semi-arid climate. Salting of an outcropping aquifer by saline groundwaters has not been studied in a specific case by the writer, and its importance as an actual process is not known. It is evident, however, that some of the aquifers had fresh waters updip and saline waters downdip, as the depositional facies changed.

The time needed for the development of the South Texas caliches is now thought to have been confined to the time intervals which elapsed between the deposition of one formation and that of the next. These times may have corresponded with, and been limited by, oscillations of sea-level, similar to those of the Pleistocene, when the streams became entrenched as sea-level fell, leaving the former levels of stream sedimentation exposed as land sur-

[1] Discussion of paper by this title and author, published in the *Bulletin*, Vol. 19, No. 3 (March, 1935), pp. 317–55; 7 figs., 4 tables.

[2] "Post-Fleming Surface Formations of Coastal Southeast Texas and South Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), pp. 651–88; 15 figs.

faces, on which caliche-bearing soils developed. Doering has evidence which seems to point to partial lithification, and local erosion of the caliches of the Pliocene before the covering beds were laid down.

Opportunities for the entrance of marine waters into eroded lower ends of the aquifers are now believed to have some positive data in support. There seems to have been a general sparseness and thinness of the Recent sediments along the continental shelves of the Atlantic and Gulf coasts of America. These deposits are known to have been trenched by streams during the Pleistocene (and Pliocene ?) oscillations of sea-level, with later filling of the canyons with water-soaked silt.

Doering and Price[3] have found that only two Recent deltas of the Texas coast have completely filled their late Pleistocene entrenched channels and begun to build a Recent delta. These are the combined Brazos-San Bernard-Colorado Recent delta (marked by Miller and Yahola soil groups, with some Harris soils) and the narrow tongue of the Rio Grande's Recent delta (Harlingen, Rio Grande, Laredo, and Raymondsville soils only). These facts indicate a light Recent deposition and strong along-shore currents which prevented the formation of convex Recent deltas like that of the Mississippi.

Francis P. Shepard's extensive studies of the records of dredging along the continental shelves has also shown that Recent deposits are, in general, limited and do not cover the coarse Pleistocene deposits exposed on the shelves.[4]

Shepard also cites the many submarine canyons of the shelves, now well surveyed and well established. These canyons seem to be of Pleistocene age, or, if older, to have been used by Pleistocene streams, with the probability that they have been kept open and scoured by the seaward return of storm tides along the bottom of the shelves. Thus, the Pliocene and Pleistocene aquifers may be open to the entry of Gulf waters at many points far out on the shelves.

A further point raised by several geologists and chemists, including F. H. Lahee and his associates of the Sun Oil Company, and Richard Davey, geologist and chemist, now with Southern Alkali Company, Corpus Christi, is that diffusion should be considered as having played a major rôle in the mixing of waters in these aquifers and in the development of regional gradients of chlorine concentration. They see molecular movements of the brine salts as more important than flow, when the water sands were closed at their lower ends—that is, under static conditions—and also under flowing conditions, the effects of flow and of diffusion going on at the same time and being additive or subtractive, according as variations in concentrations, porosities, and structural conditions determined. It is hoped that we may be given an elaboration of these views from the chemical standpoint.

W. Armstrong Price

Corpus Christi, Texas
January 28, 1936

[3] See Doering's forthcoming paper, "Revision of Pliocene and Pleistocene of South Texas." Manuscript.

[4] *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 1157–70, and Vol. 43 (1932), pp. 1003–16, with an abstract of an unpublished paper on p. 30 of "Preliminary List of Titles and Abstracts," *Geol. Soc. America* (December 26–28, 1935).

NEW THEORY OF CONTINENTAL SPREADING[1]

In the article "New Theory of Continental Spreading," in this *Bulletin* (December, 1935), the following revisions should be made.

Page 1807, 7th line from bottom, the sentence should read: "Many geologists will agree that it is probable that the original crust of the earth was closely akin to the sima and that the sial has been formed from it by oxidation, hydration, leaching and other processes in which the chief agent is percolating water, chemical action, erosion, re-sorting and re-deposition as sediments.

Page 1815, last paragraph, the first sentence and a new sentence, here added, should read: "On the other hand, the main objections to the theory would appear to be that at present it can not be demonstrated that the original crust of the earth was of sima, though there is evidence which points in this direction. Again the view put forward as to the origin of the sial will not be generally accepted."

The following is an additional note to the article.

Let us suppose that the sial was not formed in the manner put forward by the writer in the foregoing paper and that it was an original part of the crust covering the greater part of the solid earth. It is then possible to formulate a somewhat similar theory by postulating periodic accelerations in the speed of rotation of the globe about its axis for which, the writer understands, there is some astronomical evidence. In this case, however, there would be a periodic tendency of the lighter sial to move in towards the equatorial areas with, perhaps, some retraction, movement in opposed directions, and spreading during intervening times. The problem becomes much more complex.

ARTHUR WADE

PERTH, WESTERN AUSTRALIA
December 30, 1935

[1] Because of the author's distance from the place of publication, his revisions, here printed, were not received in time to be used in his article on this subject in the *Bulletin* of December, 1935, pp. 1806–18.—*Editor.*

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REVIEWS AND NEW PUBLICATIONS

* Subject indicated by asterisk are in the Association library and available to members and associates. A list of technical periodicals available for loan to members and associates was published in the *Bulletin*, Vol. 18, No. 9 (September, 1934), pp. 1215–17.

The International Congress of Mines, Metallurgy, and Applied Geology, Paris, October, 1935. Comite de Organisation, 1, Rue Mongolifier, Paris, III, France.

APPLIED GEOLOGY

The seventh session of the International Congress of Mining, Metallurgy, and Applied Geology was held at Paris from October 20 to 26, 1935. In the booklet of résumés of papers presented in the Section of Applied Geology there are abstracts of fourteen papers in the Petroleum Section. These may be arranged under the following headings.

	Papers
1. Stratigraphy and micropaleontology	3
2. Origin of oil and processes relating thereto	2
3. Occurrence of oil and related substances	6
4. Producing problems	1
5. Geophysical prospecting for oil	1
6. Oil-field map legends	1

1a.—J. Lacoste of Morocco gave a paper on the use of foraminifers in stratigraphic studies and classified the condition of the fossils due to whether the test had been altered or not, and he concluded that there should be close collaboration between the stratigrapher and the micropaleontologist, in order to avoid grave errors.

1b.—R. Potonié of Berlin reported on the results of micropaleontology in allowing the more exact determination of horizons by association of foraminifers and ostracodes in samples from oil wells and in coal and lignite deposits by means of microscopic vegetal associations.

1c.—W. L. F. Nuttall presented a paper on "Micropaleontology Applied to Stratigraphic Correlations in America." In this he called attention to the use of microfauna in correlating well samples in the Gulf Coast area and showed the analogous Tertiary fauna of Mexico, Trinidad, and Venezuela. The micropaleontologic evidence indicated an extensive transgression of the Upper Eocene sea in southern United States, Central America, the West Indies, and the northern part of South America.

2a.—Stanislas Zuber of Poland reported on "The Geochemical Processes during the Formation of Petroleum." He noted that experimental studies have only explained certain details of the commencement of naphthogenic processes and many of the peculiarities of the composition and final alteration of oil. He believes in the diversity of primary phytogenic material and likewise in various processes of alteration. Due to variations in the transformation processes the same type of primary material could give different products and *vice versa* different types of vegetal detritus might yield analogous end

products. The presence of polybitumens would mark the stopping of the process and not an intermediate stage, as generally believed.

2b.—The Japanese geologist, Jun-Ichi Takahashi, considered the question of the origin of petroliferous deposits in a rather similar manner and pointed out the presence of clays or shales with bituminous substance (kerogen) in all petroliferous regions. He emphasized the importance of pressure which would have acted in the same manner as temperature to dissociate the bituminous products, and regards the aromatic petroleum as derived from terrestrial plants and the methanic petroleum, as from "protobitumens" rich in oil and fats and naphthenic petroleum from "protobitumens" rich in seaweeds and plankton.

3a.—"Does Petroleum Exist in the Paleozoic Formations of Europe" was the subject of a paper presented by W. A. J. M. van Waterschoot van der Gracht. He noted the similarity of stratigraphic and tectonic conditions between the Appalachian Mountain chains of America and the Hercynian foreland of Permo-Carboniferous chains in Europe and admits that the search for oil in these formations of Europe is rendered difficult by the thick cover of Mesozoic and Tertiary strata. He finds conditions favorable for a source rock in the Culm of Lower Carboniferous age and notes the positive evidence of oil in the Carboniferous of Derbyshire, England (Hartstoft well), also in the Munster Basin of Germany. Two wells are now being drilled to test the Carboniferous possibilities, one at Ascheberg in Westphalia, Germany, and the other near Moll in Belgium.

3b.—The occurrence of contemporaneous asphalt in a lacustrine limestone of Lower Oligocene age at Pont-du-Château, France, was described by E. Aumaitre and Mr. Rognes.

3c.—J. Barlot reported on the bituminous rocks of the Jura region, and noted that the shales of the Lower Lias (Taorcian) and the Kimmeridgian show a mixture of organic matter which is true source material for oil deposits and suggests a common origin for oils from shales and the natural petroleums.

3d.—Professor Macovei presented a paper upon the oil deposits of the Eastern Carpathians of Roumania, in which he pointed out that the oil is in most cases a secondary deposit. He regards the black shales of the Barremian (Lower Cretaceous) and the Menilite schists of Oligocene age as probable source beds. The richest deposits are localized in the Pliocene formations of the foothill zone where diapir folds occur. These orogenic movements began with the Alpine folding and lasted to the Quaternary.

3e.—The bituminous shales of the Congo were described by G. Passau as of Trias and Rhaetic ages and occur in the northeast part of the central basin of the Congo. These deposits lose their bituminous content as they approach the center of the basin, so there is no chance for commercial oil deposits.

3f.—The natural gas fields of Transylvania were reported on by D. Ciupagea who described the various domes and the stratigraphy. (See review by I. Voitesti in November, 1935, *Bull. Amer. Assoc. Petrol. Geol.*)

4.—The problem of regeneration of the Boryslaw oil field was presented by M. O. Wyszynski of the Pionier Company of Poland. This company has been considering the question of repressuring with gas or air. The various areas of the producing fields have been studied, and the company expects soon to be able to decide upon the most favorable zones to make some trials using gas from the Daszawa field.

5.—Researches and prospecting for oil in Poland by the Pionier Company were also described by Wyszynski. He stated that the company had carried out certain geological work and wildcat drilling and also geophysical work using magnetic, gravimetric, and seismic methods. The seismic reflection work gave particularly interesting results. He concludes as a result of the geophysical studies as follows. 1. The foreland zone, that is, the land lying between the Carpathian Mountains and the Podolian Plateau, is filled with Tertiary deposits of a thickness in excess of 1,000 meters. The principal zones recognized are (a) the peri-Carpathian salt formation with folds of Flysch formation at depth, (b) the central zone of intense folding, and (c) the northern zone of gentle tectonics. 2. The presence of oil in the peri-Carpathian zone has been known for a long time in many localities. In zones (b) and (c), besides the gas field of Daszawa which has been exploited since 1924, gas is known from many places extending from the Roumanian frontier to Drohobycz. The composition of this gas leads to the hope of finding liquid hydrocarbons in this zone.

6.—S. Zuber gave a short paper upon signs used in profiles of borings. He suggested the use of colors imitating the natural tints of clay layers. To introduce color method he advised the use of colored pencils chosen according to a special code. He presented a comparison of the American and Russian systems of coloring.

MINING SECTION

Several papers were presented in the Mining Section of the congress, which dealt with the petroleum industry.

A group of papers upon operating problems at Pechelbronn were given. Comet and Orgeval described stratigraphic determinations based upon drill cuttings from the hydraulic method of drilling used at Pechelbronn. Forisier took up safety methods employed in gallery mining, and Schnaebelé made an evaluation of crude oil resources based upon exploitation by drilled wells and by galleries.

Professor Bielski of the Mining Academy at Krakow gave a paper on the history of the oil industry in Poland. He brought out the shift from dominant German capital before and during the War to French capital since the War. He also explained the changes in systems of drilling, producing and refining from the beginning in 1853 to the present.

Another professor from the Mining Academy, Naturski, described the types of torpedoes used in shooting wells in Poland to increase their production.

Two papers dealing with rotary drilling were given: one by Schulz on rotary equipment and drilling in Germany, and the other by O'Rourke dealing with rotary problems and combination drilling in hard formations of eastern United States.

C. and M. Schlumberger explained a new electrical device for measuring the dip of strata. This is lowered in a drill hole on an electric cable and allows the graphic registration of the orientation and dip of the beds in the uncased part of the hole. This has already passed the experimental stage and will soon be available to the industry.

Pierre Trouilloud gave a paper on the attempts which have been made to increase oil and gas production in France since 1918. He lists the oil and gas occurrences, as well as wildcat wells which have been drilled in each district, and gives a history of prospecting and the meters drilled and yield obtained.

GEOPHYSICAL SECTION

There was also a section of the congress devoted to geophysics. The following papers listed in the résumé under this section will doubtless be published shortly and thus be available to readers.

1. "Project of Geophysical Atlas; Recent Geophysical Studies in Alsace," by E. Rothé
2. "Electrical Prospecting of the Salt-Bearing Basin of Alsace," by C. and M. Schlumberger
3. "The Variometric Method for the Electric and Stratigraphical Exploration of the Earth," by A. Zabelli
4. "On the Application of the Electromagnetic Method for Prospecting Anticlines," by H. Galbrun and L. Cagniard
5. "On the Principles of Electromagnetic Prospecting by Alternating Current at a Very Low Frequency," by S. Stefanescu
6. "Magnetic Anomalies in Madagascar and Their Relations with Geologic Phenomena," by A. Savornin and H. Besairie
7. "Anomalies of Magnetic Declination in Vinarice Mountain and the Geological Causes," by F. Cechura
8. "Geophysical Researches in the Neighborhood of Bratislava," by F. Cechura and J. Splichal
9. "On the State of Development of Instruments for the Measurement of the Intensity of Gravity," by A. Graf
10. "Some Gravity Anomalies in Northern Java," by L. M. H. Vreugde
11. "Method and Equipment for a Chemical Process Applicable to the Researches of Petroleum Deposits," by A. Graf

Under Section VIII, "Teaching and Research Institutes," the following is of interest to petroleum geologists.

Professor J. Jung reported on "The Training of the Economic Geologists at the 'Ecole Nationale supérieure du Pétrole' in Strasbourg," and Professor Rothé on "The Teaching of Applied Geophysics at the 'Faculté des Sciences,' Strasbourg."

Tolwinski reported on the methods of work and results obtained by the Geological Survey of the Carpathians during the last 15 years, and L. Dubertret on geological work in Syria and Lebanon since the French Mandate.

Other papers presented at this congress in the various sections may interest readers of the *Bulletin*, but, since they are not closely connected with oil geology, no mention is made of them here.

W. P. HAYNES

LONDON, ENGLAND
December, 1935

"Timothy Abbott Conrad, with Particular Reference to His Work in Alabama One Hundred Years Ago." By HARRY EDGAR WHEELER. *Bull. Amer. Pal.*, Vol. 23, No. 77 (1935). Published by Paleontological Research Institution, Ithaca, New York. 157 pp., 33 illus.

Little more than one hundred years ago (February 28, 1833) in the midst of the busy cotton traffic, a steamboat on the Alabama River put ashore at Claiborne, Timothy A. Conrad, an unassuming shell collector. To-day cotton hauling on the Alabama is no more, but the bluff which Conrad more than anyone else made famous, is still the acme of American Tertiary fossil localities. The names of those which form the line of notables, who have climbed the "365" steps at Claiborne incline, become legion. The steps have been

hallowed by Judge Charles Tait, General Lafayette, Sir Charles Lyell, Philip H. Gosse, Alexander Winchell, Michael Tuomey, Eugene Hilgard, Eugene A. Smith, Truman H. Aldrich, and hosts of those who follow in the calling of fossil study. The name of Conrad is so bound with that of Claiborne that the paleontologist does not think of one without the other. To-day, in the midst of rapid transit and of detailed work, it is not only fitting and proper but important that the geologist be reminded to honor Conrad, the "Strata Smith" of the American Tertiary.

Harry E. Wheeler has written "Timothy Abbott Conrad, with Particular Reference to His Work in Alabama One Hundred Years Ago" in a fair, sympathetic, and thorough manner. Wheeler, a former member of the staff of the Alabama Museum of Natural History, friend of E. A. Smith and T. H. Aldrich, and a devotee of fossil collecting, is well qualified to give the background of Conrad's work in the South. Of additional interest to the historian is the setting of Alabama, particularly of Claiborne which led up to Conrad's visit there. Wheeler weaves naturally into the life of Conrad, the story of Claiborne, once a center of cultural and political activity. From the narrative of Conrad's labors to reach Claiborne, of his happiness there, of other naturalists' descriptions of the place, one wonders who has really given more the spirit of Claiborne, Conrad or Wheeler? It is because of this and of the inclusion of full-page illustrations of Charles Tait (discoverer of Claiborne, Gosport sand fossils), T. H. Aldrich, G. D. Harris, Isaac Lea, Samuel Morton, Thomas Say, Charles Lyell, and Phillip Gosse that the book will be of interest to the naturalist. There is a list of the plants of Claiborne Bluff by Roland M. Harper.

A reproduction of the first geological map of Alabama will be of use to the geologist. The original was made by Conrad in 1835.

Probably the most important part of the bulletin, to the systematic paleontologist, is the detailed account of the available dates relative to the controversy between Conrad and Lea over the priority of the names of the Claibornian fossils.

Conrad's poetical endeavors are given a part. Many of his short poems are included.

The book is appropriately dedicated to Professor G. D. Harris.

Considering that Conrad destroyed all records of his affairs which were in his possession, the task of collecting data on which an authentic account of his life could be written, was not easy. Wheeler has painstakingly gathered all the available facts. Some seem remote to the subject of Conrad. One might wish that biographical items of Conrad's immediate family had been brought in more fully and concisely. However, if one wants living personalities in interesting environments, read Wheeler.

KATHERINE V. W. PALMER

PALEONTOLOGICAL RESEARCH INSTITUTION
ITHACA, NEW YORK
January 10, 1936

"Zinc and Lead Deposits of Northern Arkansas." By EDWIN T. MCKNIGHT. *U.S. Geol. Survey Bull. 853* (1935). Prepared in coöperation with the *Arkansas Geological Survey*. 311 pp. 11 pls., 19 figs. For sale by the Superintendent of Documents, Washington, D.C. Price, $1.00.

This report gives the results of field investigations by the author, Edwin T. McKnight, extending over a period of several years. Attention was not alone devoted to the lead and zinc deposits themselves but also to the structure and stratigraphy of the ore-bearing and associated rocks. The section of rocks, described in detail, includes Ordovician, Silurian, Mississippian, and Pennsylvanian rocks as revealed in the Yellville Quadrangle, where most of the zinc and lead deposits have been developed. The report is accompanied by a colored geologic map of that quandrangle, a structure-contour map of the quadrangle, and a table showing the names and equivalents of formations in the zinc and lead region of northern Arkansas. The report gives new conclusions concerning some of the stratigraphic problems in the Yellville Quadrangle and adjoining areas. It, therefore, will be of interest to all geologists desiring information concerning the structure and stratigraphy of the southern Ozark region of northern Arkansas.

The Devonian system is not represented in the more richly mineralized districts, and the Silurian formations are thin and discontinuous. The Ordovician and Carboniferous systems, however, are well represented. The stratigraphic column in the Yellville Quadrangle includes a maximum of 2,400 feet of rocks, divided into 19 formations. There are 12 well established unconformities. The occurrence of so many unconformities has produced numerous discontinuities in the distribution of the formations. In general, the stratigraphic breaks recorded in the unconformities increase in amount from south to north. The rocks show a low regional dip toward the south, more marked in the Ordovician beds than in the Carboniferous beds. Locally, gentle folding and faulting (normal faulting) have occurred. The faults are post-Pennsylvanian, except one that is post-Ordovician and pre-Mississippian. Some of the folds had their inception in the Ordovician period and have been accentuated at least three times.

Chief among the new stratigraphic conclusions of the author are those relating to the Everton, St. Peter, Joachim, and Jasper formations, of Ordovician age. The St. Peter sandstone of the Yellville Quadrangle was demonstrated by him to be continuous with the St. Peter of the Batesville district,[1] near the east edge of the Ozark region of Arkansas, and was found by him to thin westward and disappear in the southwest corner of the Yellville Quadrangle. The Everton formation, lying below the St. Peter, continues westward beyond the western border of St. Peter exposures and it includes, in the Eureka Springs and Harrison quadrangles, the sequence of rocks that were designated by A. H. Purdue and me[2] as Everton limestone, St. Peter sandstone, Joachim limestone, and possibly the Jasper limestone. In consequence the so-called Joachim limestone of these quadrangles is a portion of the Everton formation and the so-called St. Peter of these quadrangles becomes a member of the Everton; the St. Peter sandstone of these quadrangles has been named the Newton sandstone member by McKnight. The Jasper limestone retains its rank as a formational unit. Although its true stratigraphic position is not known—whether of Everton age, of post-Everton-pre-

[1] H. D. Miser, "Deposits of Manganese Ore in the Batesville District, Arkansas," *U. S. Geol. Survey Bull. 734* (1922).

[2] A. H. Purdue, and H. D. Miser, "Description of the Eureka Springs and Harrison Quadrangles, Arkansas-Missouri," *U. S. Geol. Survey Eureka Springs-Harrison Folio 202* (1916).

St. Peter, or of post-Joachim-pre-Plattin age—it is tentatively placed by the author between the Everton and St. Peter.

The Everton formation of northern Arkansas as now constituted includes three named sandstone members, all composed of saccharoidal sandstone and similar in character to the St. Peter. These lie at different horizons and are not coextensive areally, either with one another or with the St. Peter. These members and their principal areas of exposures are (1) the Kings River sandstone, 0 to 40 feet thick, lying at the base of the formation in the Eureka Springs Quadrangle but lying 50 feet above the base in the Harrison Quadrangle; (2) the Newton sandstone, 0 to 150 feet thick, occupying a position as much as 200 feet above the base of the Everton formation in the Eureka Springs, Harrison, and Yellville quadrangles; and (3) the Calico Rock sandstone, 0 to 150 feet thick, exposed in a wide area between Cotter and Evening Shade, Arkansas.[3] This area of the Calico Rock sandstone is east of the Yellville Quadrangle and the base of the sandstone, according to McKnight, lies about 150 feet above the base of the Everton at Norfork, Arkansas.

The Everton, Jasper, St. Peter, and Joachim formations constitute the Buffalo River series of E. O. Ulrich, which he has placed between the Beekmantown and Chazy of the New York section.

HUGH D. MISER

WASHINGTON, D. C.
January 31, 1936

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*"Systematic Packing of Spheres—with Particular Relation to Porosity and Permeability." By L. C. GRATON and H. J. FRASER. "Experimental Study of the Porosity and Permeability of Clastic Sediments." By H. F. FRASER. *Jour. Geol.* (Chicago, Illinois), Vol. 43, No. 8, Pt. I (November–December, 1935), pp. 785–1010; 49 figs. Price, $1.00.

To anyone who finds pleasure in increasing his breadth of understanding of physical substances and the laws of physics, Part I of the November–December, 1935, issue of the *Journal of Geology*, consisting of the papers, "Systematic Packing of Spheres—with Particular Relation to Porosity and Permeability," by L. C. Graton and H. J. Fraser, and "Experimental Study of the Porosity and Permeability of Clastic Sediments," by H. J. Fraser, will be most delightfully entertaining. For these papers are full of interesting observations and experiments which are indeed illuminating with respect to the geometrical structure of porous media. However, if the reader has been looking for a discussion leading to explicit quantitative results of direct applicability to practical problems, he will probably decide that his search is not yet ended, even after having completed this 225 page miniature treatise on the porosity and permeability of assemblages of spheres and of clastic sediments.

Perhaps the first significant impression made on a reader of this issue who has been following the earlier literature of the same subject is that Slichter's classic paper in the United States Geological Survey of 1897–98 was really not at all as exhaustive as commonly supposed, and that indeed the problem of the packing of uniform spheres is considerably more complex than that

[3] A. W. Giles, "St. Peter and Older Ordovician Sandstones of Northern Arkansas," *Arkansas Geol. Survey Bull. 4* (1930), pp. 113–52.

formulated by Slichter. Thus, whereas the latter supposed all types of uniform sphere packing to correspond to intermediate cases of a general rhombohedral packing, whose extremes give the simple cubic and hexagonal lattices of porosities 47.64 and 25.95 per cent, it is here shown that there are four fundamentally distinct types of packing, namely, the cubic, orthorhombic, rhombohedral, and tetragonal-sphenoidal, of porosities: 47.64, 39.54, 25.95, and 30.19 per cent, respectively. These four cases—generalized to six for convenience in discussion—are described in detail and figures are given to show both the external appearance of the sphere groupings in the unit cells and the internal voids of the cells.

Quite interesting is the discussion of the relative stability of the various types of packing, in which it is pointed out that Slichter's generalized rhombohedron for intermediate packings would be quite unstable, and that of the four fundamental types the tightest or rhombohedral form is the most stable, as is indeed confirmed empirically. This question naturally leads to that of the most probable packing that would be obtained if no attempt is made to construct a particular lattice. Here it is observed that the building up of an assemblage of spheres consists essentially in a conflict between the tendency to form "colonies" of tight hexagonal packing and the tendency to produce haphazard packing. The resultant mode of packing actually obtained in any given case will depend upon, in addition to the stability of the individual ideal types, the nature of the bottom layer of spheres, the manner in which the spheres are laid down, the rapidity of assembly, and the detailed shape of the container walls. While the significance of the individual effects cannot be quantitatively evaluated, the propagation of either the colony formation of ideal types or of haphazard distributions is determined by their resultant action.

From the point of view of cultural instruction the treatment of the problem of the permeability of the various packings of homogeneous spheres is most fascinating. The drawings of the cross sections of the different types of pores as the pores are traversed and of the views of the through-ducts to be seen along various directions of packing assemblies are certainly artistic and illuminating. However, more stress might have been appropriately put on the fact that the anisotropy in the permeability associated with the differences in these sections is of nothing more than academic significance, and should not be confused with the commonly found anisotropy in the permeability of consolidated heterogeneous sands. On the other hand, it is to be noted that the emphasis on the effect of the container wall on the marginal pores and the resultant permeability of an unconsolidated sand are indeed well placed.

The reviewer thoroughly agrees with the critique by L. C. Graton and H. J. Fraser of Slichter's theoretical derivation of a "permeability formula." For it is true that his geometrical representation of the voids in a general type of packing was too simple, and his analysis of the flow in these voids was only approximate. But if the analysis of Slichter's simplified picture could be carried through only approximately, then is it not merely wishful optimism that would lead one to hope, as must the authors, since they urge further research of Slichter's type, that the much more complex correct representation could be given a satisfactory analytical treatment? And even if this were possible, is it likely that one could extrapolate the results to mixtures of spheres? And even if our unbounded enthusiasm for mathematical ingenuity and

omnipotence leads us to believe that the calculation of the permeability of mixtures of spheres could be successfully accomplished, should we be so naïve as to think that what is after all the only problem of practical interest, namely the problem of the permeability of heterogeneous sand mixtures, composed of a *distribution* of *non-spherical* grains, the voids in which are almost literally indefinable and undescribable without a microscopic photograph of each and every pore, could also be treated mathematically? Or, perhaps, would it not be wiser to become disillusioned at once and with deep humility and penitence confess our mathematical limitations and appeal directly to the unaesthetic and colorless but omniscient arbiter of all physical questions, namely experiment? Perhaps the time that would be saved by an experimental measurement of the permeability of a specimen of a porous medium might even better be used to find means of soothing our pride, wounded by the admission of our inability to *compute* the numerical value of such a simple property of a porous medium as its permeability.

Of course, it is difficult for the reviewer to concede appreciably more reliability to the formula of Fair and Hatch, although its manner of derivation is obviously based upon the explicit recognition of the futility of a detailed mathematical computation of the permeability by the classical hydrodynamics. On the other hand, without questioning the independence of the derivation of their formula by Fair and Hatch, it may be observed that J. Kozeny had deduced the same variation of the permeability k, with the porosity f, that is, $k = \text{const.}\ f^3/(1-f)^2$, by quite similar arguments as early as 1927 (*Wasserkraft u. Wasserwirtschaft*, 22, 86, 1927).

Hurrying briefly over the paper on "The Porosity and Permeability of Clastic Sediments" by H. J. Fraser, it is pleasing to record that the experiments on, and the qualitative discussion of, the factors governing porosity, such as absolute grain size, their distribution, their shapes, and the method of depositions, are most instructive and interesting. Although no issue can be taken with the author's demonstration that the various permeability "formulas" fail to predict correctly the permeabilities measured with heterogeneous sands, this conclusion has, of course, been well recognized for some time except by those who had a particular formula to perpetuate (*cf.* J. Kozeny, *op. cit.*, where it is shown that even his own formula may also be seriously in error).

As to the factors affecting permeability it may be noted that insofar as the permeability of a porous medium has meaning, the effects of temperature and hydraulic gradient are quite definite and invariable. For, by definition, the flow is *viscous* only if it is directly proportional to the hydraulic gradient—the permeability is independent of the gradient—, and the term permeability in a significant analytical sense loses its meaning when the flow becomes turbulent. Furthermore, when the flow is viscous, the flow must be inversely proportional to the viscosity of the fluid, and only as the temperature affects the latter does it enter the problem (in the case of liquids). On the other hand, it is the feeling of the reviewer that the viscosity of the fluid should be divorced from the definition of the permeability of the porous medium, which should refer to a fluid of *unit* viscosity, and hence be independent of the character of the fluid passing through the medium. The latter is then completely defined by its permeability, regardless of the nature of the fluid, and whether it be gas or liquid.

With regard to permeability variations in the bulk of a porous medium, the author very appropriately points out that the apparent anisotropy of a sand caused by a synthesis of the composite sand from several isotropic layers of different permeability—the pertinent formulas for which are explicitly derived—should not be confused with that inherent in the individual layers. For while the former will be such that the permeability parallel to the bedding planes will *always* exceed that across them, the anisotrophy of the individual layers, as determined by the manner of deposition and nature of the sand grains, may give permeabilities parallel to the bedding planes either greater or less than that normal to them. Thus of the 65 measurements of consolidated samples parallel and perpendicular to the bedding planes recorded by Fancher, Lewis, and Barnes (*Penn State Bull. 12*, 1933) 19 showed permeabilities normal to the bedding planes in excess of those parallel to them. In view of such variations in the character of consolidated sands, the extended discussion by Fraser on "The Depositional Effects on Local Permeability" is most welcome.

An interesting section discussing qualitatively the penetration of sediments by ore-bearing solutions closes the issue.

The authors are to be congratulated for their lucid and stimulating treatments of questions which have hitherto lacked a critical analysis. Anyone interested in the physical sciences will find these papers pleasantly diverting as well as instructive.

MORRIS MUSKAT

GULF RESEARCH AND DEVELOPMENT COMPANY
PITTSBURGH, PENNSYLVANIA
February 2, 1936

RECENT PUBLICATIONS

CALIFORNIA

*"A Geologic Section Across the Southern Peninsular Range of California," by William J. Miller. *California Jour. Mines and Geol.* (San Francisco), Vol. 31, No. 2 (April, 1935), pp. 115–42; 8 figs.; 1 pl.

CHILE

"A New Lower Cretaceous Fauna from Copiapo, Chile," by Helmut Winkler. *Centralblatt f. Min. usw.* (Stuttgart), Abt. B (1935), pp. 114–19; 3 figs. In German.

COLOMBIA

"Stratigraphy of Eastern Cordillera of Colombia," by W. O. Dietrich. *Centralblatt f. Min. usw.* (Stuttgart), Abt. B (1935), pp. 74–82; 1 fig.

EGYPT

*"The Pleistocene Fauna and Flora of Kharga Oasis, Egypt," by Elinor W. Garner. *Quar. Jour. Geol. Soc. London*, Vol. 91, Pt. 4 (December 27, 1935), pp. 479–518, pls. 30–34.

ENGLAND

*"The Base of the Gault in Sussex," by J. F. Kirkaldy. *Quar. Jour. Geol. Soc. London*, Vol. 91, Pt. 4 (December 27, 1935), pp. 519–537; 2 figs. Trans-

gressive overlap in Lower Cretaceous. "It is suggested that these facts indicate that the growth of the Wealden dome may have commenced in Albian times."

*"The Stratigraphy and Tectonics of the Cross Fell Inlier," by Frederick William Shotton. *Ibid.*, pp. 639–590; 10 figs., 1 pl. (geological map in colors). The rocks in the district are Paleozoic and Permo-Triassic.

GENERAL

*"Die Bedeutung der Forschungsarbeiten auf dem Gebiete der Erdöle" (Importance of Research in Petroliferous Regions), by Stanislav v. Pilat. *Petrol. Zeit.* (Vienna), Vol. 32, No. 4 (January 22, 1936), pp. 1–4.

**Petroleum Vademecum*, 11th edit. (1936), 2 vols., compiled by Robert Schwarz. Verlag für Fachliteratur Ges.m.b.H., 147, Wilhelmstrasse, Berlin SW. 68 and 4, Vegagasse, Vienna XIX/1. Price for 2 volumes: Austrian schilling, 50; M24; £2; $10. The eleventh edition of *Petroleum Vademecum*, compared with the previous 10 editions shows a complete revision of most of the book, especially regarding tariffs on mineral oil in the various countries, statistics on production, refining, import and export of oil products, and consumption. The section "Drilling Engineering" contains tables with API and German standards for rigs, drill pipes, pipe lines, tool joints, wire ropes, et cetera. Entirely new is the chapter "Nomenclatures" as well as the complete list of all the refineries of the world. The most important head lines of the tables, for example, the chemical-physical part for conversion of the various measures used in the oil industry, are written in German, English, and French.

"Stratigraphy of Recent Deep-Sea Sediments in Equatorial Atlantic Ocean," by Wolfgang Schott. *Zeit. Deutsch. Geol. Gesellschaft* (Stuttgart), Vol. 87 (1935), pp. 278–79. In German.

*"Appraising the Oil Industry's Future," by Lester C. Uren. *World Petrol.* (New York), Vol. 7, No. 1 (January, 1936), pp. 6–13; 5 figs.

**Tertiary Faunas. Vol. 1. The Composition of Tertiary Faunas*, by A. Morley Davies. "A textbook for oilfield palaeontologists and students of geology." 406 pp., 565 figs. 5.5×8.75. Cloth. Thomas Murby and Company, 1 Fleet Lane, London, E. C. 4. Price, 22£, 6 sh, net.

*"Les lois de déclin et l'estimation de la production future d'un puits de pétrole" (The Laws of Decline and the Estimation of Future Production of Petroleum Wells), by M. W. Tiraspolsky. *Annales des Mines* (Paris, June, 1935). 32 pp. 8 figs. Dunod, 92, Rue Bonaparte (vi), Paris.

GEOPHYSICS

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"Geology of Cameron and Vermilion Parishes," by Henry V. Howe and James H. McGuirt. *Louisiana Geol. Survey Bull. 6* (New Orleans, 1936). Contains list of maps covering southwest Louisiana and complete bibliography.

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"Geologic Maps and Report on Osage County, Oklahoma," by N. W. Bass, L. E. Kennedy, W. R. Dillard, Constance Leatherock, *et al. U. S. Geol. Survey Public Works Project, 1934–1935* (1936). Three maps and brief preliminary report on subsurface geology in Osage and Kay counties, Oklahoma, and Cowley, Butler and Greenwood counties, Kansas, with particular reference to Bartlesville and Burbank sandstones. May be purchased from the director of the U. S. Geological Survey, Washington, D. C. Price, $3.50, payable in advance.

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**Bull. Geol. Survey Poland* (Warsaw), Vol. 8, No. 2 (1935). 223 pp., 24 figs., 9 pls. In Polish, French, and German. 7×10 inches. Paper. Contains: "Geological Structure of the Vicinity of Turka on the Stryj, Carpathia," by T. Chlebowski, pp. 1–26; "Sulphur Deposits in Czarkowy," by R. Krajewski, pp. 27–66; "Quaternary in the Region between the Carpathians and Sambor," by H. Teisseyre, pp. 67–88; "The Most Important Stratigraphic and Paleontologic Problem of the Polish Tortonian," by J. Czarnocki, pp. 99–206; "Age and Fauna of the Salt Formation of Wieliczka," by K. Kowalewski, pp. 207–23.

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*"Das Rohöl und die Schwereanomalien in den polnischen Westkarpathen" (Petroleum and Anomalies of Density in the Polish Western Carpathians), by Jan Nowak. *Ibid.*, pp. 9–10; 1 fig.

RUSSIA

*"On the Mountain Ranges of Northeastern Asia," by J. A. Bilibin. *Problems of Soviet Geology* (Moscow), Vol. 5, No. 12 (December, 1935), pp. 1079–85. In Russian.

*"Contributions to the Question of the Mechanics of Folding," by V. K. Livanov. *Ibid.*, pp. 1086–94. In Russian.

*"On the Cretaceous Deposits of the Peninsula Kamchatka," by B. F. Diakov. *Ibid.*, pp. 1103–14. In Russian.

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"Fauna of Syrian Cretaceous, Eocene, and Oligocene," by Max Blanckenhorn. *Centralblatt f. Min. usw.* (Stuttgart), Abt. B (1935), pp. 148–61. In German.

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*"The Orogenic History of Central Utah," by Edmund M. Spieker. *Science* (New York), Vol. 83, No. 2142 (January 17, 1936), pp. 62–63.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Fort Worth, Texas), Vol. 10, No. 1 (January, 1936).
"Calcareous Green Algae from the Upper Cretaceous of Tripoli (North Africa)," by Julius Pia.

"Some Hamilton (Devonian) Crinoids from New York," by Winifred Goldring.
"Cambrian Trilobites from Northwestern Wyoming," by B. Maxwell Miller.
"New Trilobite Genera from the Bonneterre Dolomite (Upper Cambrian) of Missouri," by Christina Lochman.
"Three New Miocene Dogs and Their Phylogeny," by Frederic B. Loomis.
"New Monactinellid Sponges from the Ordovician of Wisconsin," by B. F. Howell and R. W. Landes.
"Notes on the Devonian Crinoid Fauna of the Cedar Valley Formation of Iowa," by L. R. Laudon.

**Journal of Paleontology* (Fort Worth, Texas), Vol. 10, No. 2 (March, 1936).

"*Schwagerina* versus *Pseudoschwagerina* and *Paraschwagerina*," by Carl O. Dunbar and John W. Skinner.
"Actinopterygian Jaws from the Mississippian Black Shales of the Mississippi Valley," by Chalmer L. Cooper.
"Fusulinids from the Black Hills and Adjacent Areas in Wyoming," by M. L. Thompson.
"Ostracoda from the Chouteau Formation of Missouri," by Philip S. Morey.
"Some Fusulinid Problems," by M. P. White.
"Rudistids from the Cretaceous of Northern Santa Clara Province, Cuba," by M. G. Rutten.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 3 (MARCH, 1936), PP. 332-381

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Alton R. Mornhinveg, Houston, Tex.
Henry V. Howe, M. C. Israelsky, John S. Ivy
Karl William Reynolds, Tulsa, Okla.
Joseph E. Morero, R. B. Rutledge, Richard T. Lyons

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August F. Beck, A. N. Murray, Stuart Sherar
H. Travis Brown, Oklahoma City, Okla.
L. R. McFarland, John E. Van Dall, William W. Clawson
Fred A. Devin, Holdenville, Okla.
Darsie A. Green, Clyde M. Becker, Ira H. Cram
Henry Martin Kilian, Norman, Okla.
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Ira A. Brinkerhoff, Corpus Christi, Tex.
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Olin Derryl Brooks, Houston, Tex.
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R. Clare Coffin, R. J. Riggs, Thos. W. Leach
Constance Leatherock, Tulsa, Okla.
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Floyd A. Nelson, St. Louis, Mo.
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J. H. Van Zant, R. L. Clifton, Harry E. Lillibridge
Maria Frances Spencer, Midland, Tex.
E. Russell Lloyd, James FitzGerald, Jr., John Emery Adams
Thomas Eugene Wall, Oklahoma City, Okla.
Robert M. Whiteside, Ward C. Bean, Clark Millison

PAPERS FOR THE BULLETIN

Many of our members believe or have thought that it was necessary that all papers be presented at the March meeting of the Association prior to publication; and others are under the impression that only rather long, formal, and complete papers were desired for publication in our *Bulletin*.

While the most desirable procedure is for an author to present his article to the Association at the annual meeting and then turn the manuscript over to the editor, this is not a prerequisite to publication and at any time authors may submit papers to the *Bulletin* for publication without having presented them at the annual meeting. Furthermore, it is particularly desirable that shorter papers, geologic notes, brief preliminary descriptions of new discoveries, improvements in technique, and other items of current interest be submitted for publication. The Geological Notes section of the *Bulletin* is set aside for just such items and gives everyone an opportunity to contribute short, informal comment with a minimum of effort.

A. I. LEVORSEN

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FINANCIAL STATEMENT, 1935

To the EXECUTIVE COMMITTEE,

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, TULSA, OKLAHOMA.

Dear Sirs:

We have examined the accounting records of THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS for the year ended December 31, 1935, and now submit the following statements:

Exhibit

A	Statement of Financial Condition as at December 31, 1935
B	Statement of Income for the year ended December 31, 1935
C	Statement of Income from Publications for the year ended December 31,1935
D	Statement of General and Administrative Expenses for the year ended December 31, 1935

Schedule[1]

I	Inventory—Printed Matter—December 31, 1935
II	Investments—December 31, 1935

Cash in Banks was reconciled to confirmations obtained direct from the depositories and includes funds temporarily deposited in interest-bearing accounts; Reserves of $1,477.40 have been provided for Accounts Receivable from Members and Others; Inventories of Printed Matter are priced at appraised values in accordance with the resolution adopted by your Executive Committee and represent publications required for anticipated needs; Investments were verified by inspection or confirmations received from the depositories and are stated at the lower of cost or market at December 31, 1935.

The net profit for the year ended December 31, 1935, of $5,690.73 includes Extraordinary Items in the net amount of $5,076.91, summarized below:

Adjustment of Reserve for Bond Investment to lower of cost or market		$4,765.13
Less: Loss on Disposal of Bonds		2,257.82
		$2,507.31
Recovery of Delinquent Dues previously charged off	$2,820.00	
Less: Cost of Back Number Bulletins purchased for Members who paid delinquent dues (original supply inadequate)	250.40	2,569.60
		$5,076.91

The adjustment of Reserve for Bond Investment to lower of cost or market, $4,765.13, represents that portion of reserve provided prior to the current year, which is in excess of the amount necessary to show investment in bonds at the lower of cost or market at December 31, 1935. During the year the Association collected or reinstated membership dues, which had been charged off in prior years, in the amount of $2,820.00, which amount has been reduced by $250.40 representing the cost of back-number bulletins purchased for such members, the original supply of bulletins having been exhausted. The Executive Committee at a meeting held December 28, 1935, authorized a refund of 50 cents per copy for unavailable monthly bulletins for the years 1933 and 1934 to members who paid their dues for these years but did not receive such bulletins. The amount authorized to be refunded has not been determined at the date of this report, and as such amount is not readily ascertainable no provision has been made in the attached statements for such refund.

The Association has contracted for the printing of *Geology of Tampico Region* and the cost thereof of approximately $2,500.00 is not reflected in this report.

In our opinion and subject to the foregoing, the accompanying Statement of Financial Condition and related Statements of Income and Expenses correctly reflect the financial condition of THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS at December 31, 1935, and the results of its operations for the year ended on that date.

Yours very truly,
(Signed) ARTHUR YOUNG & CO.
Accountants and Auditors

TULSA, OKLAHOMA
February 7, 1936

[1] Schedules I and II are not printed.—*Editor.*

EXHIBIT A

STATEMENT OF FINANCIAL CONDITION AS AT DECEMBER 31, 1935

ASSETS

	General Fund	*Publication Fund*	*Research Fund*	*Total*
CURRENT ASSETS:				
Cash in Banks:				
The First National Bank and Trust Company, Tulsa, Oklahoma	$14,168.86	$ 3,148.39	$ —	$17,317.25
National Bank of Commerce, Tulsa, Oklahoma	456.06	—	—	456.06
	$14,633.92	$ 3,148.39	$ —	$17,782.31
The First National Bank and Trust Company, Tulsa, Oklahoma:				
Certificate of Deposit—Due May 26, 1936	7,500.00	—	—	7,500.00
Savings Account (Temporary)	2,529.19	—	—	2,529.19
TOTAL CASH IN BANKS	$24,663.11	$ 3,148.39	$ —	$27,811.50
Accounts Receivable:				
Members (*Less* Reserve for Doubtful Accounts $1,192.00)	$ 519.00	$ —	$ —	$ 519.00
Advertising (*Less* Reserve for Doubtful Accounts $177.00)	368.25	—	—	368.25
Printed Matter (*Less* Reserve for Doubtful Accounts $108.40)	773.15	503.64	—	1,276.79
Miscellaneous	30.85	20.82	—	51.67
TOTAL ACCOUNTS RECEIVABLE	$ 1,691.25	$ 524.46	$ —	$ 2,215.71
Accrued Interest Receivable (*Less* Reserve $1,089.16)	$ 281.38	$ 110.25	$ 23.93	$ 415.56
Inventory—Printed Matter:				
Bulletins, etc. Cost	$36,298.25	$ 6,252.34	$ —	$42,550.59
Less: Reserve therefor	20,960.80	—	—	20,960.80
Net Value	$15,337.45	$ 6,252.34	$ —	$21,589.79
Special Publications in Process				
Gulf Coast Volume	—	365.98	—	365.98
Geology of Tampico Region	—	384.88	—	384.88
	$15,337.45	$ 7,003.20	$ —	$22,340.65
TOTAL CURRENT ASSETS	$41,973.19	$10,786.30	$ 23.93	$52,783.42
INVESTMENTS:				
At Lower of Cost or Market				
Cost	$26,531.33	$14,435.02	$1,416.72	$42,383.07
Less: Reserve	1,868.61	2,214.30	20.00	4,102.91
TOTAL INVESTMENTS	$24,662.72	$12,220.72	$1,396.72	$38,280.16
FIXED ASSETS:				
Furniture and Fixtures	$ 3,653.82	$ —	$ —	$ 3,653.82
Less: Reserve for Depreciation	2,404.54	—	—	2,404.54
TOTAL FIXED ASSETS	$ 1,249.28	$ —	$ —	$ 1,249.28
PREPAID INSURANCE	$ 59.92	$ —	$ —	$ 59.92
TOTAL ASSETS	$67,945.11	$23,007.02	$1,420.65	$92,372.78

EXHIBIT A

STATEMENT OF FINANCIAL CONDITION AS AT DECEMBER 31, 1935

LIABILITIES AND SURPLUS

	General Fund	*Publication Fund*	*Research Fund*	*Total*
CURRENT LIABILITIES:				
Accounts Payable	$ 1,159.39	$ 27.30	$ —	$ 1,186.69
Accrued Printers Charges: Gulf Coast Volume	—	363.10	—	363.10
TOTAL CURRENT LIABILITIES	$ 1,159.39	$ 390.40	$ —	$ 1,549.79
DEFERRED INCOME:				
Active Membership Dues—1936 and 1937	$ 6,390.50	$ —	$ —	$ 6,390.50
Associate Membership Dues—1936 and 1937	922.00	—	—	922.00
1936 Subscriptions to Bulletins	2,281.48	—	—	2,281.48
Prepaid Advertising	275.00	—	—	275.00
Subscriptions to Bound Volume XIX	491.60	—	—	491.60
TOTAL DEFERRED INCOME	$10,360.58	$ —	$ —	$10,360.58
SURPLUS:				
Balance December 31, 1934	$53,412.19	$20,150.53	$1,208.96	$74,771.68
Net Profit for the year ended December 31, 1935—Exhibit *B*	3,012.95	2,466.09	211.69	5,690.73
Balance December 31, 1935	$56,425.14	$22,616.62	$1,420.65	$80,462.41
TOTAL LIABILITIES AND SURPLUS	$67,945.11	$23,007.02	$1,420.65	$92,372.78

EXHIBIT B
STATEMENT OF INCOME FOR THE YEAR ENDED DECEMBER 31, 1935

	General Fund				*Publication Fund*		*Research Fund*		*Total*	
	Members	*Annual Dues*								
OPERATING INCOME:										
DUES:										
Associate Membership										
Less than Three Years	100	$ 6.00	$ 600.00		$—		$ —		$ 600.00	
Three to Six Years	208	8.00	1,664.00		—		—		1,664.00	
Over Six Years	62	10.00	620.00		—		—		620.00	
	370			$ 2,884.00		$ —		$ —		$ 2,884.00
Active Membership	1,586	10.00		15,860.00		—		—		15,860.00
	1,956			$18,744.00		$ —		$ —		$18,744.00
Deduct: Transfer to Income from Bulletins—										
Associate Membership	370	$ 6.00	$2,220.00		$ —		$ —		$2,220.00	
Active Membership	1,586	6.00	9,516.00		—		—		9,516.00	
	1,956			11,736.00		—		—		11,736.00
				$ 7,008.00		$ —		$ —		$ 7,008.00
PUBLICATIONS—Net Income Exhibit *C*				3,431.37		805.52		—		4,236.89
CONVENTION RECEIPTS (Net)				70.50		—		—		70.50
TOTAL OPERATING INCOME				$10,509.87		$ 805.52		$ —		$11,315.39
GENERAL AND ADMINISTRATIVE EXPENSES—Exhibit *D*				13,036.08		40.50		57.60		13,134.18
NET OPERATING INCOME—*Loss*				*$−2,526.21*		$ 765.02		*$−57.60*		*$−1,818.79*
NON-OPERATING INCOME:										
Interest on Investments			$1,504.71		$719.65		$ 61.79		$2,286.15	
Miscellaneous			138.96		7.50		—		146.46	
				1,643.67		727.15		61.79		2,432.61
NET INCOME—*Loss* BEFORE EXTRAORDINARY ITEMS				*$ −882.54*		$1,492.17		$ 4.19		$ 613.82
EXTRAORDINARY ITEMS:										
Adjustment of Bond Investment to Lower of Cost or Market			$3,648.71		$908.92		$207.50		$4,765.13	
Profit—*Loss* on Disposal of Bonds			*−2,322.82*		65.00		—		*−2,257.82*	
			$1,325.89		$973.92		$207.50		$2,507.31	
Recovery of Delinquent Dues previously charged off			$2,820.00		$ —		$ —		$2,820.00	
Less: Cost of Back Number Bulletins purchased for Members who paid delinquent dues (Original supply inadequate)			250.40		—		—		250.40	
			$2,569.60		$ —		$ —		$2,569.60	
				3,895.49		973.92		207.50		5,076.91
Net Profit Transferred to Surplus—Exhibit *A*				$ 3,012.95		$2,466.09		$211.69		$ 5,690.73

EXHIBIT C

STATEMENT OF INCOME FROM PUBLICATIONS FOR THE YEAR ENDED DECEMBER 31, 1935

	General Fund		*Publication Fund*		*Total*	
OPERATING INCOME:						
Dues Transferred:						
Associate Membership	$ 2,220.00		$ —		$ 2,220.00	
Active Membership	9,516.00		—		9,516.00	
		$11,736.00		$ —		$11,736.00
Sale of Bulletins:						
Subscriptions	$ 3,554.04		$ —		$ 3,554.04	
Advertising	4,628.46		—		4,628.46	
		8,182.50		—		8,182.50
Sale of Bound Volumes and Special Publications:						
Bound Volumes	$ 2,249.76		$ —		$ 2,249.76	
Back Numbers	738.14		—		738.14	
Structure Volume I	—		549.26		549.26	
Structure Volume II	629.71		—		629.71	
Geology of California	—		682.15		682.15	
Problems of Petroleum Geology	1,917.21		—		1,917.21	
Geology of Natural Gas	—		4,353.40		4,353.40	
Other Publications	23.50		14.50		38.00	
		5,558.32		5,599.31		11,157.63
TOTAL OPERATING INCOME		$25,476.82		$5,599.31		$31,076.13
OPERATING COSTS:						
Manager's Salary (Proportion)	$ 2,500.00		$ —		$ 2,500.00	
Editorial Salary	3,414.40		—		3,414.40	
Cost of Printing Bulletins (Including paper stock furnished by the Association $846.50)	10,468.02		—		10,468.02	
Cost of Engraving	1,965.41		—		1,965.41	
Cost of Printing Separates	394.66		—		394.66	
Stencil Corrections and Mailing	146.30		—		146.30	
Geology of Natural Gas—Printing, Binding, etc.	—		9,679.99		9,679.99	
Binding Volume XVIII	362.69		—		362.69	
Copyright Fees	24.00		—		24.00	
Bulletin Mailing and Express	762.56		—		762.56	
Other Publications—Freight and Express	311.30		—		311.30	
Discount on Publications	51.65		12.20		63.85	
Miscellaneous Bulletin Expense	32.31		—		32.31	
Printers charges for holding type on Geology of California	—		95.00		95.00	
	$20,433.30		$9,787.19		$30,220.49	
Add:						
Inventory Decrease—*Increase*	1,612.15		*—4,993.40*		*—3,381.25*	
Total Cost of Publications Sold		22,045.45		4,793.79		26,839.24
Net Income from Publications—Transferred to Exhibit *B*		$ 3,431.37		$ 805.52		$ 4,236.89

EXHIBIT D

STATEMENT OF GENERAL AND ADMINISTRATIVE EXPENSES FOR THE YEAR ENDED DECEMBER 31, 1935

GENERAL FUND:		
Manager's Salary (Proportion)		$ 2,081.32
Clerical Salaries		5,541.48
Office Rent		600.00
Telephone and Telegraph		361.84
Postage		1,389.90
Office Supplies and Expenses		476.16
Printing and Stationery		388.43
Donations—		
Society of Economic Paleontologists and Mineralogists	$530.00	
Society of Petroleum Geophysicists	250.00	
National Research Council	250.00	
		1,030.00
Executive Expense		151.69
Audit Expense		300.00
Insurance		132.60
Freight and Express		104.99
Bad Debts		43.40
Miscellaneous		26.73
Personal Property Taxes—Year 1934 (Paid under protest)		22.68
Depreciation of Furniture and Fixtures		365.00
Loss on Disposal of Furniture and Fixtures		19.86
Total General Fund		$13,036.08
PUBLICATION FUND:		
Bad Debts		40.50
RESEARCH FUND:		
Expenses of Research Committee		57.60
Total Transferred to Exhibit *B*		$13,134.18

FINANCIAL STATEMENT, DIVISION OF PALEONTOLOGY AND MINERALOGY, 1935

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS,
DR. GAYLE SCOTT, SECRETARY-TREASURER

Pursuant to your instructions I have audited the records of the secretary-treasurer of the Society of Economic Paleontologists and Mineralogists for the period January 1, 1935, through December 31, 1935, and herewith submit my report.

In my opinion this statement is true and correct. All checks were supported by voucher and were properly endorsed. All monies are carried in The Fort Worth National Bank.

Stock of journals on hand is protected by $6,000.00 fire insurance, expiring May 29, 1936.

I found the books and records well kept and the information readily available.

FORT WORTH, TEXAS
January 20, 1936

Respectfully submitted,
(Signed) L. A. DUNAGAN

RECEIPTS

Cash on hand, January 1, 1935		$3,347.24
Membership dues	$1,269.80	
Donations—A.A.P.G.	530.00	
Subscriptions—Journ. of Paleontology	2,196.05	
Subscriptions—Journ. of Sed. Petrology	943.99	
Advertising	217.18	
Paleontology dues collected	31.00	
Plates and separates	112.33	
Collections—Texas State Warrant	6.00	
Interest earned—savings account	60.66	5,367.01
Transferred from savings account		1,000.00
		$9,714.25

DISBURSEMENTS

Secretarial and clerical	$ 570.00	
Office supplies	1.70	
Postage and permit deposits	226.95	
Printing and stationery, office	61.85	
Reprints	53.98	
Insurance on stock of journals	20.30	
Refunds of dues and subscriptions	13.20	
Miscellaneous	13.50	
Plates and separates	36.47	
Audit	25.00	
Refund—Paleontological Society for dues paid S.E.P.M.	43.00	
Binding	7.15	
Returned items	6.40	$1,079.50
Printing:		
Journal of Paleontology		
December, 1934	$ 515.95	
March, 1935	445.62	
June, 1935	636.84	
September, 1935	898.32	2,496.73
Journal of Sedimentary Petrology		
December, 1934	$ 350.91	
April, 1935	289.63	
August, 1935	312.66	953.20
Transferred to savings account		1,000.00
Total disbursements		$5,529.43
Cash on deposit, Fort Worth National Bank		$4,184.82

SAVINGS ACCOUNT

Balance, January 1, 1935	$2,681.96	
Interest earned	60.66	
Transferred from checking account	1,000.00	3,742.62
Withdrawn		1,000.00
Balance, December 31, 1935		$2,742.62

ASSETS

Journals		
Stock of Journal of Paleontology	$16,824.00	
Stock of Journal of Sedimentary Petrology	4,485.00	$21,309.00
Bills Collectible		
Membership dues	48.00	
Sale of Journals	90.00	
(60) Journal of Sedimentary Petrology subscribers	180.00	
Advertising	63.25	
Plates for authors' separates	49.50	430.75
Total assets		$21,739.75

FINANCIAL STATEMENT, GEOPHYSICS DIVISION, 1935

DR. B. B. WEATHERBY, PRESIDENT,
SOCIETY OF PETROLEUM GEOPHYSICISTS,
TULSA, OKLAHOMA

Dear Sir:

Pursuant to instructions received, we have made an audit of the financial transactions of the treasurer of the Society of Petroleum Geophysicists for the period from January 1, 1935, to December 31, 1935, inclusive.

Our examination did not embrace a confirmation by correspondence of dues from members and delinquents in respect thereto.

Exhibit A [not here printed] is a statement of dues receivable from January 1, 1935, to December 31, 1935, inclusive. The list of members[1] and "back dues" are taken from the records of the treasurer.

Summaries of the "Dues Receivable" account and cash transactions are presented below.

DUES RECEIVABLE:		
Back dues	$ 434.00	
Less: due from dropped members	165.00	
		$ 269.00
Current dues		1,109.00
Total		$1,378.00
Collections—back dues	$ 224.00	
Collections—current dues	961.00	1,185.00
Delinquent	$ 194.00	
Refund due	1.00	$ 193.00
CASH TRANSACTIONS:		
Receipts:		
Balance—January 1, 1935		$ 630.46
Collections—back dues	$ 224.00	
Collections—current dues	961.00	
Collections—dues in advance	10.00	
Subscriptions	51.00	
Sales of back numbers	107.53	
Advertising	246.00	
A.A.P.G. donation	250.00	1,849.53
Total		$2,479.99
Disbursements:		
Printing and stationery	$ 589.31	
A.A.P.G.—Geophysics Symposium (special reprints)	338.54	
Secretarial work	124.75	
Miscellaneous	90.07	$1,142.67
Cash on hand—December 31, 1935		$1,337.32
Checking account	$1,037.32	
Savings account	300.00	
Total	$1,337.32	

Faithfully yours,
(Signed) FRAZER AND TORBET
Certified Public Accountants
Members, American Institute of Accountants

TULSA, OKLAHOMA
January 15, 1936

[1] Exhibit A lists total membership as 244, of whom 17 were dropped, leaving a net total of 227.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
MEMBERSHIP LIST

MARCH 7, 1936

HONORARY MEMBERS

The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues.—*Sec. 6, Article III, of the Constitution.*

LIFE MEMBERS

The executive committee may grant life membership to members who have paid their dues and are otherwise qualified.—*Sec. 2, Article III, of the Constitution.*

On the payment of three hundred dollars ($300.00) any member in good standing shall be declared a life member and thereafter shall not be required to pay annual dues.—*Sec. 2, Article I, of the By-Laws.*

MEMBERS

Any person engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, or in sciences fundamental to petroleum geology, and in addition has had the equivalent of three years' experience in petroleum geology or in the application of these other sciences to petroleum geology or to research in petroleum geology or technology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee, and provided further that these requirements shall not be construed to exclude teachers and research workers in recognized institutions whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

Active members alone shall be known as members.—*Sec. 1, Article III, of the Constitution.*

ASSOCIATES

Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, is eligible to associate membership, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in petroleum geology; and any person who is a graduate of an institution of collegiate standing, in which he has done his major work in sciences fundamental to petroleum geology or petroleum technology, and who has had the equivalent of one year's experience in the application of his science to the study of petroleum geology, shall be eligible to associate membership, provided at the time of his application for membership he shall be engaged in investigations in the broader subject of petroleum geology and technology.

Associate members shall be known as associates.

Associates shall enjoy all the privileges of membership in the Association, save that they shall not hold office; sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Association in professional cards or professional reports or otherwise.—*Sec. 3, Article III, of the Constitution.*

HONORARY MEMBERS

(**Deceased)

Campbell, Marius R., 511 Seventh St., N., St. Petersburg, Fla.
Decker, Charles E., 508 Chautauqua Ave., Norman, Okla.
**Dumble, E. T.
Goodrich, Harold B., 1628 S. Cincinnati, Tulsa, Okla.
Harris, Gilbert D., Dept. of Geology, Cornell University, Ithaca, N. Y.
Hill, Robert T., c/o Dallas News, Dallas, Tex.
Mendenhall, Walter C., U. S. Geological Survey, Washington, D. C.
Orcutt, W. W., Union Oil Company Bldg., Los Angeles, Calif.
Ordoñez, Ezequiel, Abraham Gonzales 79, Mexico City, Mexico
**Salisbury, R. D.
Schuchert, Charles, Yale University, New Haven, Conn.
Smith, George Otis, Box 308, Skowhegan, Me.
Taff, Joseph A., Associated Oil Co., 79 New Montgomery St., San Francisco, Calif.
**Udden, Johan August
**von Höfer, Hans Hofrat
**White, David
**White, I. C.

COMPLETE LIST OF MEMBERS, ASSOCIATES, HONORARY MEMBERS, AND LIFE MEMBERS

Honorary	11
Life	2
Members	1742
Associates	421
Total	2176

EXPLANATION OF SYMBOLS

*Honorary member. †Life member. ‖Associate. Members are not marked. The year refers to the date of election to the Association.

‖Abbott, John L., 1209 Fort Worth Natl. Bank Bldg., Fort Worth, Tex. '27
‖Absher, K. B., 1608 W. Pine Ave., Wichita, Kan. '25
Absher, William F., Geological Dept., Empire Gas & Fuel Co., Bartlesville, Okla. '20
Ackers, A. L., Stanolind Oil & Gas Co., Box 1410, Fort Worth, Tex. '25
Adams, Elmo W., Bin H, Taft, Calif. '30
Adams, Frank C., Gem Oil Co., 1506 Esperson Bldg., Houston, Tex. '27
Adams, John Emery, Drawer R, Midland, Tex. '29
Adams, W. C., Deep Rock Oil Corp., Atlas Life Bldg., Tulsa, Okla. '24
Addison, Carl C., 3032 N. Twenty-first St., Kansas City, Kan. '30
‖Adkisson, Albert, 1816 W. T. Waggoner Bldg., Fort Worth, Tex. '34
Adler, Joseph L., Independent Expl. Co., 2011 Esperson Bldg., Houston, Tex. '30
Aguerrevere, Pedro I., Sur 3, No. 94, Caracas, Venezuela, S. A. '24
Aguerrevere, Santiago E., Sur 3, No. 94, Caracas, Venezuela, S. A. '24
Aimer, James D., Box 375, Nacogdoches, Tex. '26
Ainsworth, David, 146 S. Fountain Ave., Wichita, Kan. '23
Aitken, W. Ernest, Room 2514, 135 E. Forty-second St., New York, N.Y. '32
Albertson, Maurice M., Shell Petr. Corp., Box 2099, Houston, Tex. '20
Albrecht, Helmuth, Burbach Kaliwerke Aktiengesellschaft, Kaiser-Otto-Ring 9, Magdeburg, Germany '32
Aldrich, G. Frank, Box 622, Midland, Tex. '25
Alexander, C. I., Magnolia Petr. Co., Drawer 872, Lake Charles, La. '27
Allan, John Andrew, University of Alberta, Edmonton, Alta., Canada '30
Allan, Thomas H., 314 Bitting Bldg., Wichita, Kan. '24
Allen, Alton C., 2609 Wabash, Fort Worth, Tex. '35
Allen, Devere F., 3000 Sowers Court, Topeka, Kan. '29

Allen, E. G., 4015 University Blvd., Dallas, Tex. '17
‖Allen, Stanley R., 215 B. Humble Bldg., Houston, Tex. '35
Allison, A. P., Sun Oil Co., 820 Esperson Bldg., Houston, Tex. '21
Althaus, H. E., Bataafsche Petr. Mij., Pladjoe, Sumatra (Res. Palembang), D. E. I. '28
Ambrose, A. W., Empire Gas & Fuel Co., Bartlesville, Okla. '19
Ames, Edward W., Box 169, San Antonio, Tex. '19
Anderson, Amil A., 6075 Franklin Ave., Hollywood, Calif. '22
Anderson, Carl B., 1131 S. Owasso, Tulsa, Okla. '19
Anderson, Carl C., Box 2025, Amarillo, Tex. '32
Anderson, Frank M., 58 Hillcrest Road, Berkeley, Calif. '24
Anderson, G. E., Dept. of Geology, University of Oklahoma, Norman, Okla. '24
Anderson, Ray Ball, Box 174, Ardmore, Okla. '24
Anderson, W. D., Amerada Petr. Corp., Box 1366, Midland, Tex. '27
Andrau, E. W. K., 2109 Kingston Drive, Houston, Tex. '32
Andrews, Philip, Venezuela Gulf Oil Co., Ciudad Bolivar, Venezuela, S. A. '25
‖Angle, W. M., 1811 Esperson Bldg., Houston, Tex. '30
Applin, Paul L., 2200 Edwin Ave., Fort Worth, Tex. '19
Argabrite, William Graeme, Box 33, Lewisburg, W. Va. '28
Arick, Millard B., Drawer W, Midland, Tex. '27
Armstrong, Earle N., 3902 Cheyenne Road, Amarillo, Tex. '33
Armstrong, Harold K., Room 838, 727 W. Seventh St., Los Angeles, Calif. '27
Armstrong, J. M., Box 545, Midland, Tex. '18
Arnold, Emmett L., Box 72, McAllen, Tex. '27
‖Arnold, Henry C., British American Oil Prod. Co., Philtower Bldg., Tulsa, Okla. '30
Aronson, Sam M., Atlantic Oil Prod. Co., 701 Magnolia Bldg., Dallas, Tex. '24
Athy, Lawrence F., Geophysical Division, Continental Oil Co., Ponca City, Okla. '26
Atkinson, William H., 26th Floor Ramsey Tower, Oklahoma City, Okla. '22
Aurand, Harry A., 1350 Bellaire St., Denver, Colo. '26
Aurin, Fritz L., Southland Royalty Co., Ponca City, Okla. '17
Autry, Vernon E., Fain-McGaha Oil Corp., 607 Hamilton Bldg., Wichita Falls, Tex. '26
Avery, C. Dwight, U. S. Geological Survey, 3240 Interior Bldg., Washington, D. C. '28
Ayers, Floyd M., Gulf Production Co., Midland, Tex. '30

Bace, A. C., Stanolind Oil & Gas Co., Philcade Bldg., Tulsa, Okla. '24
Bacon, Charles S., Jr., Geological Dept., Riverside Junior College, Riverside, Calif. '29
Baden, Martin W., Box 520, Winfield, Kan. '21
Bader, G. E., 857 Humble Bldg., Houston, Tex. '34
Bagg, Rufus M., Box 386, Appleton, Wis. '27
Bailey, James P., N.V. Ned. Pac. Petr. Mij., 26 Tanah Abang West, Batavia-Centrum, Java, D.E.I. '31
‖Bailey, Joe E. L., 1201 E. Eleventh St., Winfield, Kan. '30
Bailey, Thomas L., Shell Petr. Corp., Shell Bldg., St. Louis, Mo. '24
Bailey, Willard F., Box 1208, Midland, Tex. '35
Bain, H. Foster, 29 W. Thirty-ninth St., New York, N. Y. '26
Baird, Chester A., Apartado 234, Venezuela Gulf Oil Co., Maracaibo, Venezuela, S. A. '21
Baker, Arthur A., U. S. Geological Survey, Washington, D. C. '30
Baker, Norval E., Iraq Petr. Co., Ltd., City Gate House, Finsbury Square, London, E. C. 2, England '27
Baker, Raymond F., Geological Dept., The Texas Co., 135 E. Forty-second St., New York, N. Y. '17
Baker, William A., Jr., Geological Dept., Huasteca Petr. Co., Apartado 94, Tampico, Tamps., Mexico '24
Bakke, W. E., Oklahoma Oil Corp., McCullough Bldg., Okmulgee, Okla. '28
Baldwin, E. B., Arkansas Fuel Oil Co., Box 283, Houston, Tex. '29
Bale, Hubert E., 220 N.W. Thirty-first St., Oklahoma City, Okla. '24
Ball, Max W., First Natl. Bank Bldg., Denver, Colo. '19
Ballard, James L., Stanolind Oil & Gas Co., 1132 Milam Bldg., San Antonio, Tex. '25
Ballard, William Norval, 1433 S. Keeler, Bartlesville, Okla. '29
Banks, Thomas R., 326 Furr Drive, San Antonio, Tex. '27
Barbat, William F., Standard Oil Co., Taft, Calif. '28
Barlow, Victor, 121 N. Hill St., Los Angeles, Calif. '27

Barnes, Chester F., Box 306, Big Spring, Tex. '35
Barnes, Roy M., Continental Oil Co., 601 W. Fifth St., Los Angeles, Calif. '24
Barnett, D. G., Geological Dept., United Production Corp., Beeville, Tex. '25
‖Barnett, J. A., The Texas Co., Houston, Tex. '28
Barnhart, Carl F., Geophysical Research Corp., Box 2040, Tulsa, Okla. '29
‖Barragy, Edward J., 2502 Hazard St., Houston, Tex. '31
Barret, William M., 2524 Fairfield Ave., Shreveport, La. '32
Barrow, Leonidas T., 3314 Chevy Chase Drive, Houston, Tex. '22
Bartell, Laurence D., East Texas Refg. Co., Longview, Tex. '27
Bartle, Glenn G., University of Kansas City, Kansas City, Mo. '27
Bartlett, C. Lothrop, Sun Oil Co., Beaumont, Tex. '28
Bartlett, Fred W., Shell Petr. Corp., Shell Bldg., Houston, Tex. '24
Barton, Donald C., Humble Oil & Refg. Co., Box 2180, Houston, Tex. '20
Barton, Louis A., 342 Albany St., Shreveport, La. '20
Bartosh, E. J., Bankline Oil Co., 634 S. Spring St., Los Angeles, Calif. '28
Bartram, John G., Stanolind Oil & Gas Co., Casper, Wyo. '17
Bartram, Paul L., Phillips Petr. Co., Box 152, Shawnee, Okla. '27
Barwick, John S., 139 N. Lorraine, Wichita, Kan. '24
Bass, N. W., Box 311, Tulsa, Okla. '25
Bassett, Charles F., 6121 Holmes St., Kansas City, Mo. '28
Bateman, Alan M., Yale University, Drawer 91-A, Yale Station, New Haven, Conn. '20
‖Bates, R. P., 404 Springer Bldg., Tulsa, Okla. '30
Bauermann, Max K. H., Carel van Bylandtlaan 30, The Hague, Holland '27
Bauernschmidt, A. J., Magnolia Petr. Co., Box 111, Houston, Tex. '27
‖Baughman, George W., Phillips Petr. Co., 610 Ellis Singleton Bldg., Wichita, Kan. '36
Bay, Harry X., Illinois Geological Survey, Urbana, Ill. '30
Beal, Carl H., 650 S. Grand Ave., Los Angeles, Calif. '19
Bean, Ward C., Box 1191, Tulsa, Okla. '18
Beatty, Robert M., 3703 Graustark, Houston, Tex. '27
Beck, A. F., Carter Oil Co., Box 801, Tulsa, Okla. '27
Beck, Elfred, 1323 S. Frisco, Tulsa, Okla. '20
Beckelhymer, Roy L., 2235 Robinhood St., Houston, Tex. '26
Becker, Clyde M., 224 S. Fourteenth St., Chickasha, Okla. '21
Beckwith, H. T., 547 Subway Terminal Bldg., Los Angeles, Calif. '21
Beede, J. W., c/o L. O. Todd, Court Arcade, Tulsa, Okla. '19
Beekly, Albert L., Box 381, Tulsa, Okla. '19
Beers, Roland F., 1311 Republic Bank Bldg., Dallas, Tex. '31
Behre, Charles H., Jr., Northwestern University, Evanston, Ill. '29
Belknap, Ralph L., University of Michigan, Ann Arbor, Mich. '31
Bell, Alfred H., State Geological Survey, Urbana, Ill. '28
Bell, Harry Wesley, Box 471, Rodessa, La. '22
Bell, Olin G., Box 548, Laredo, Tex. '20
Belluigi, Arnaldo, R. Osservatorio Geofisico, Catania, Sicily '31
Belt, Ben C., 3451 Del Monte Drive, Houston, Tex. '19
Bending, Ralph E., Y.M.C.A., Wichita, Kan. '25
Bendrat, T. A., 91 S. Kanawha St., Beckly, W. Va. 21'
Benedum, Darwin, 414 W. Elsmere Pl., San Antonio, Tex. '27
‖Benson, Don G., Sinclair-Prairie Oil Co., Box 1242, Amarillo, Tex. '31
‖Benson, Edmund T., State Geological Survey, Urbana, Ill. '31
‖Benson, Floyd P., 121 E. Oklahoma, Blackwell, Okla. '31
Benton, L. B., 1730 Sixth Ave., Fort Worth, Tex. '20
Bentz, Alfred, Invalidenstr. 44, Berlin N. 4, Germany '34
Berger, Walter R., 1005 Fort Worth Natl. Bank Bldg., Fort Worth, Tex. '17
Bernard, W. E., Box 661, Tulsa, Okla. '21
Bernoulli, W., 57 Sissacherstrasse, Basle, Switzerland '24
Berry, George F., Jr., Geological Dept., Empire Oil & Refg. Co., El Dorado, Kan. '36
‖Berry, Harry L., 2503 W. Park Pl., Oklahoma City, Okla. '30
Berwald, W. B., U. S. Bureau of Mines, Bartlesville, Okla. '23
‖Berwick, James D., Box 801, Tulsa, Okla. '36
Best, J. Boyd, Route 1, Box 420, Houston, Tex. '21
Bevier, George M., 1517 Shell Bldg., Houston, Tex. '21

Bickel, C. Russell, Shell Petr. Corp., Box 417, McPherson, Kan. '27
Biraud, F., Cie Francaise des Petroles, 11, rue du Doctor Lancereaux, Paris, France '31
‖Bird, Helen Pier, Humble Oil & Refg. Co., Drawer W, Midland, Tex. '35
‖Birdsong, Peyton M., 1522 Grand Ave., Fort Worth, Tex. '30
Birk, Ralph A., 811 City Natl. Bank Bldg., Wichita Falls, Tex. '20
Birkhauser, Max, Shell Oil Co., Oilfields, Calif. '26
Black, Jo Pat, 1810 Petroleum Bldg., Houston, Tex. '32
‖Blackburn, Willis C., Box 142, Crowley, La. '28
Blackwelder, Eliot, Box N, Stanford University, Calif. '19
Blanchard, W. Grant, 329 Wilson Bldg., Dallas, Tex. '18
Blanpied, B. W., Drawer 1731, Shreveport, La. '23
‖Blau, Ludwig W., 2027 Colquitt, Houston, Tex. '30
Bleecker, Edward S., 1615 Whitehall Bldg., 17 Battery Pl., New York, N. Y. '21
Blodget, Ward B., 707 Petroleum Securities Bldg., Tenth & Flower Sts., Los Angeles, Calif. '24
Bloesch, Edward, 840 Kennedy Bldg., Tulsa, Okla. '17
‖Bloomfield, George D., 1227 W. Fiftieth St., Los Angeles, Calif. '35
‖Boehms, E. F., 805 San Angelo Natl. Bank Bldg., San Angelo, Tex. '31
Bohart, Philip H., Gypsy Oil Co., Box 661, Tulsa, Okla. '23
Bohdanowicz, Charles, Str. Polna 64, Warsaw, Poland '31
Bolyard, Garrett L., Barnsdall Oil Co., Tulsa, Okla. '27
Bong, Carl P., Hoard Expl. Co., 623 Esperson Bldg., Houston, Tex. '27
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Wright, Hugh, 1008 Second Natl. Bank Bldg., Houston, Tex. '30
‖Wright, Randall, R.D. 1, Box 8, Ventura, Calif. '35
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Wylie, James R., Jr., 2711 Grant Bldg., Pittsburgh, Pa. '21
Wyman, Everett A., Box 995, Wichita, Kan. '24
Wynn, Warren H., Sinclair Prairie Oil Co., Box 5030, Shawnee, Okla. '26

Yager, Charles E., Box 2110, Fort Worth, Tex. '24
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Yoakam, Coler A., Box 1162, Oklahoma City, Okla. '22
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‖Young, C. T., 410 S. Church St., Cordell, Okla. '27
Young, Jackson S., Box 1422, Monroe, La. '28
Young, Karl E., 713 Esperson Bldg., Houston, Tex. '26
Young, Wilber H., 103 W. Main St., Titusville, Pa. '35

Zaba, Joseph, Rio Bravo Oil Co., Houston, Tex. '33
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Ziebold, William O., 1572 Virginia St., Charleston, W. Va. '29
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Zimmerman, C. C., The Texas Co., Box 2332, Houston, Tex. '31
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Zoller, H. E., Shell Petr. Corp., Box 1191, Tulsa, Okla. '25
Zoller, Lawrence J., Box 2306, Tulsa, Okla. '21
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Zuber, Stanislav, Hotel Boston, Rome, Italy '31

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 3 (MARCH, 1936), P. 382

Memorial

CHARLES D. GLEASON

Charles D. Gleason, geologist, Missouri Geological Survey, and First Lieutenant 110th Field Artillery, Missouri National Guard, died in Rolla, Missouri, September 11, 1935. On September 1 he underwent an operation for appendicitis and for several days appeared to be on the road to recovery. Complications followed, however, from which he did not recover.

He was born in Aurora, Illinois, February 9, 1908, and attended the University of Missouri from 1925 to 1929, where he majored in geology and received the degree of Bachelor of Arts. He was engaged in post-graduate work in that institution from 1929 to 1931 and received the degree of Master of Arts in geology. He became associated with the Missouri Geological Survey at Rolla in June, 1931, and for the past few years he had been actively engaged in both field and subsurface laboratory work pertaining to the ground-water resources of the state.

During the past 2 years he was charged with very responsible work and in that time had made marked advancement in his profession. He was rapidly becoming an authority on the complex subsurface conditions in eastern Missouri, as well as an authority on pertinent ground-water problems in various parts of the state. His opinions regarding geological problems were highly valued, both by his associates and by the drilling fraternity, with whom he came in daily contact. The latter recognized him as an authority on their problems and sought his candid opinion regarding them.

A few months before his death, his first formal report, "Underground Waters in St. Louis County, and the City of St. Louis, Missouri," was published, and he had accumulated a great deal of information that he planned to incorporate in future reports.

In 1933 he became an associate member of the American Association of Petroleum Geologists and was also a junior member of the American Institute of Mining and Metallurgical Engineers. He was an honorary member of the Missouri Water Well Drillers Association and annually took an active part in the convention and the preparations incidental thereto of that organization. He was also a member of the Pi Kappa Alpha social fraternity.

In addition to his geological work he was intensely interested in his duties as an officer of the Missouri National Guard, and shortly would have been promoted to the rank of captain. Services for him were conducted by fellow officers of his regiment and in accordance with full military procedure.

Charles D. Gleason possessed a wide circle of friends and his personality and ever ready smile endeared him to those with whom he came in contact. As a mutual friend has so aptly expressed it—"There can never be too much of the good will and kind spirit in this world which Gleason possessed." It is difficult to understand why the work of one so young, so full of promise, and so active in his chosen field should terminate at such an early age.

H. S. McQUEEN
Assistant State geologist

ROLLA, MISSOURI
January 30, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 3 (MARCH, 1936), PP. 383-384

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

CONSTANCE LEATHEROCK, recently with the United States Geological Survey at Tulsa, Oklahoma, is now micropaleontologist with the Tide Water Oil Company at Tulsa.

THOMAS C. HIESTAND, with W. C. McBride, Inc., Tulsa, has accepted a position with the Indian Territory Illuminating Oil Company at Bartlesville, Oklahoma.

President A. IRVING LEVORSEN, of Tulsa, Oklahoma, and secretary-treasurer E. C. MONCRIEF, of Wichita, Kansas, have recently visisted several geological societies in Oklahoma and Texas. President Levorsen presented his paper on "The Time of Oil Migration and Accumulation," and secretary Moncrief spoke on Association affairs. These meetings were attended by exceptionally large numbers of geologists in the local districts and are considered of distinct benefit to the affiliated societies and the Association. The schedule was as follows: January 13, Oklahoma City Geological Society; January 20, Tulsa Geological Society; January 30, Fort Worth Geological Society; February 1, West Texas Geological Society at Midland; February 3, Panhandle Geological Society at Amarillo; February 4, North Texas Geological Society at Wichita Falls.

P. A. MEYERS has accepted a position with the Pan American Production Company, with headquarters at Corpus Christi, Texas.

"The Geology of the Stonewall Quadrangle," by GEORGE D. MORGAN, one of the important publications on Oklahoma geology, is now available through the Oklahoma Geological Survey, according to ROBERT H. DOTT, director. The report, commonly referred to as "Morgan's report," was published in 1924 by the Bureau of Geology, Norman, as *Bulletin 2*.

HERBERT HENRY BRADFIELD, geologist with The Texas Company, has been transferred from Wichita Falls, to Fort Worth, Texas.

HERMAN A. FONVILLE, geologist with the Bridwell Oil Company, has been transferred from Wichita Falls, to San Antonio, Texas.

J. A. MCCUTCHIN, Panhandle District exploitation engineer for Shell Petroleum Corporation, gave a paper entitled "The Relation of Earth Temperatures to Geological Structure" before the Panhandle Geological Society at their monthly meeting held January 23.

HENRY N. TOLER, formerly assistant supervisor of the Mississippi State Oil and Gas Board, has been appointed to fill the unexpired term ending June, 1936, of GEORGE C. SWEARENGEN, who died January 10.

R. C. QUIETT, formerly geologist with the Indian Territory Illuminating Oil Company, at Seminole, Oklahoma, is vice-president of the Victor Drilling Tool and Supply Company, and may be addressed at Box 330, Shawnee, Oklahoma.

W. BLAIR MCCARTER, formerly with the Humble Oil and Refining Company, at Houston, is now with the Tide Water Oil Company, at Lafayette, Louisiana.

PAUL D. TORREY, consulting engineer of Bradford, Pennsylvania, has been retained to supervise Diamond drilling and laboratory testing of cores taken from producing properties of Dominion Petroleum Company, Ltd., in Middlesex County, Ontario, Canada.

MORELAND T. HARTWELL, formerly geologist with the Transcontinental Oil Company, is now with The Texas Company, at Wichita Falls, Texas.

C. W. TOMLINSON, consulting geologist of Ardmore, Oklahoma, presented a paper entitled "The Major Geologic Features of Southern Oklahoma," before the Ardmore Geological Society, February 4, and an illustrated lecture on "Geology of Southern Oklahoma," before the Mid-Continent Royalty Owners Association at Tulsa, February 11.

A new "Wilcox" oil pool has been discovered in Oklahoma underlying the old, shallow Billings pool in the Phillips-Shell McCaughtry No. 1, located in the NW. ¼, NE. ¼, NE. ¼, Sec. 21, T. 23 N., R. 2 W., Noble County, Oklahoma. It started flowing at a rate of 1,370 barrels per hour together with 40–50 million feet of gas from the "Wilcox" sand found at 4,242–56 feet. This discovery is the result of subsurface geological reasoning and in addition to the geological departments of the Phillips and Shell companies, was foreseen by the geological departments of the Tide Water, Pure, and Continental oil companies, all of whom acquired leases in what appears to be the producing belt, in advance of the discovery.

At a recent meeting of the Kansas Geological Society, Wichita, Kansas, the following officers were elected for the year 1936: president, R. A. WHORTAN, with Tom Johnson, 705 Fourth National Bank Building; vice-president, CHARLES W. ROOP, Indian Territory Illuminating Oil Company, 605 Union National Bank Building; secretary-treasurer, B. S. RIDGEWAY, Empire Oil and Refining Company, 409 Kaufman Building.

The Rocky Mountain Association of Petroleum Geologists, Denver Colorado, elected the following officers for the coming year: president, ROSS L. HEATON, 2374 Elm Street, Denver; first vice-president, W. C. TOEPELMAN, University of Colorado, Boulder; second vice-president, H. W. OBORNE, Box 57, Colorado Springs; and secretary, J. HARLAN JOHNSON, Box 336, Golden, Colorado.

J. ELMER THOMAS has moved his office from 512 Milam Building, San Antonio, to 1010 Electric Building, Houston, Texas.

HUGO R. KAMB has resigned his position in the United States Engineers Office at St. Paul, Minnesota, to join the geological staff of the Shell Petroleum Corporation as subsurface geologist at Shreveport, Louisiana.

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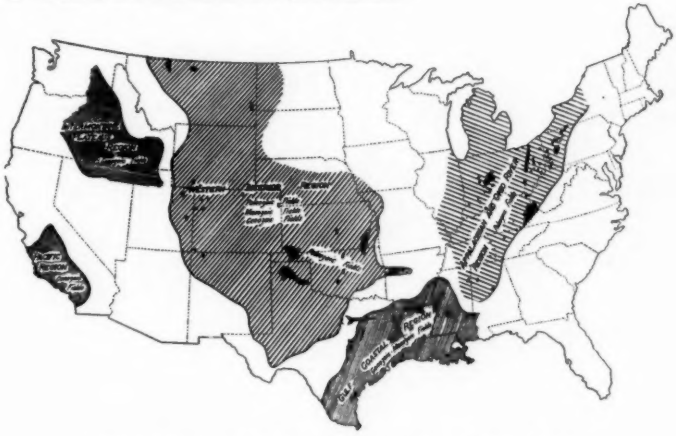

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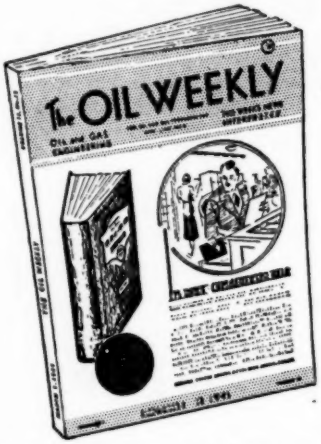

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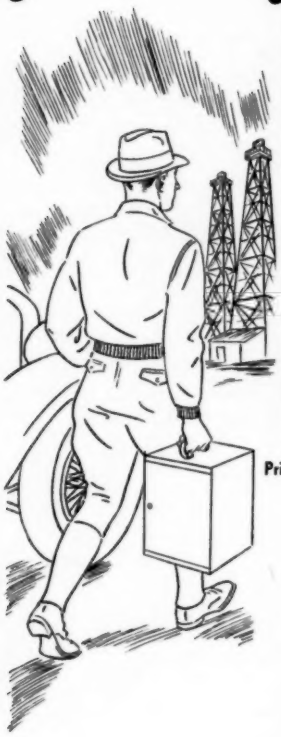

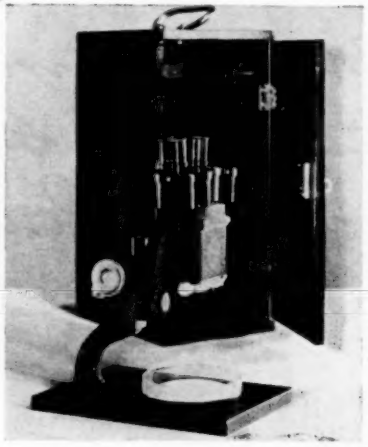

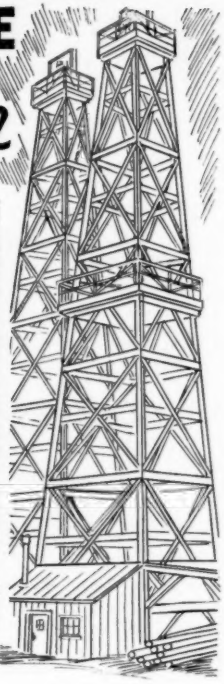

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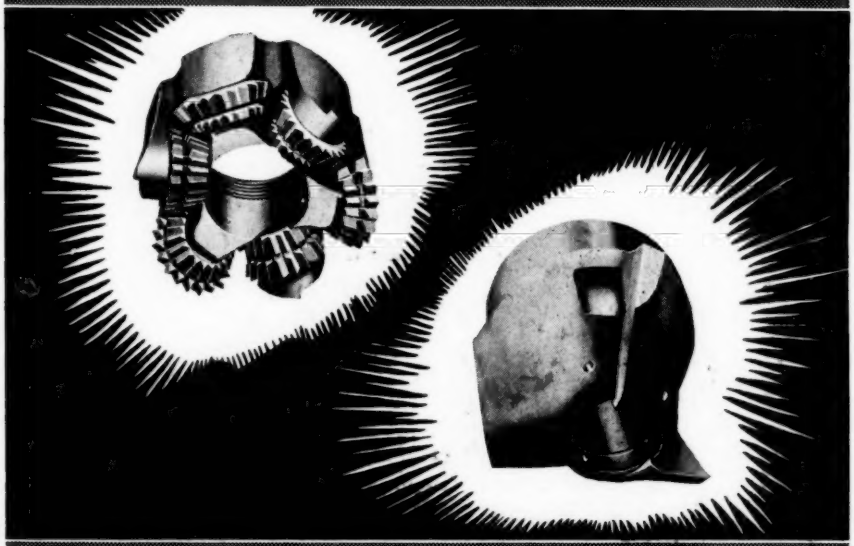

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